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On the Tectonics of the Southern Midlands.

By R. H. RASTALL, M.A., Sc.D., M.Inst.M.M., F.G.S.

> "The geological structure of these islands is the result of movement superimposed upon movement."
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> "Several of the movements followed old axes of disturbance, lines of weakness dating from an early period in the history of the globe; and again, some of the latest disturbances of which we have cognizance were but renewals of movement along the same general lines."—SIR A. STRAHAN, British Association, Cambridge, 1904.

IN any purely stratigraphical treatment of a tectonic problem one of the greatest of the initial difficulties is always that of deciding where to begin, and in the present case this difficulty is unusually acute, since the primary object of the investigation is an endeavour to trace back phenomena occurring in later ages to causes of long antecedent origin. In more precise language, the object aimed at is to show that certain structural features of the Mesozoic rocks of the southern Midlands of England can be attributed to the recurrence of activity along old-established fold-lines of very early date.

This thesis has already been expounded with great clearness by Sir Aubrey Strahan on two occasions; firstly, in his address to Section C of the British Association at Cambridge in 1904, and secondly, in his Presidential Address to the Geological Society of London in 1913: also by Professor Kendall in his brilliant and illuminating contribution to the Final Report of the Coal Commission,[1] published in 1905. It has also been utilized by myself in a section of *Geology in the Field*, the Jubilee Volume of the Geologists' Association, 1910. Since that date, however, some further information has come to hand from various sources, and a more exhaustive study of the facts has convinced me that the theories put forward by the writers mentioned can be amplified and amended in certain important respects, such emendations being not only of theoretical interest, but possibly of value in connexion with the search for hidden coalfields beneath the Mesozoic strata of the region here dealt with.

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[1] Final Report of the Royal Commission on Coal Supplies. Part IX. Report of the Geological Committee upon the Resources of the Concealed and Unproved Coalfields of the United Kingdom, 1905. [Cd. 2361.] Subsequently cited, for the sake of brevity, as *Final Report of the Coal Commission*, 1905.

The first part of this paper will be devoted mainly to a discussion of the geology of a region comprised within the 1 inch sheets Nos. 170, 171, 185, 186, 202, and 203 of the Ordnance Survey maps, in the counties of Northampton, Warwick, Bedford, and Buckingham; incidental references will also be made where necessary to parts of Leicestershire, Cambridgeshire, Hertfordshire, and Oxfordshire. The second part of the paper will contain a more general discussion of the inferences to be drawn from the data available from Part I and from other sources, with special reference to the distribution of Palaeozoic rocks beneath the Mesozoic covering of the southern Midlands in general, and the possible economic applications thereof.

PART I.

The surface geology of the region as above defined is shown in a manner well adapted for the present purpose in the *Index Map* of the Geological Survey on the Scale of 4 miles to 1 inch, sheets 11, 12, 15, and 16.

Within this area there are a certain number, unfortunately a rather small number, of deep borings, put down in search of water or coal. Though not numerous, these borings are believed to afford the key to the problem in hand. The formations seen at the surface range from the Trias to the Chalk, while in the northern part there are small exposures of Palaeozoic and Pre-Cambrian rocks. To the south and south-east again a number of deep bores have revealed the Palaeozoic rocks forming the London platform, against which the Mesozoic subdivisions are banked up, with a well-marked overlap: the first of the Mesozoic series known to pass completely over this old land is the Gault, which indicates the beginning of the great Cenomanian transgression. Details of nearly all the borings hitherto published will be found in the *Report* of the Coal Commission, in Sir A. Strahan's Address to the Geological Society, already cited, and in Mr. Lamplugh's Presidential Address to the same Society for 1919. Much useful information is also contained in the Memoir of the Geological Survey entitled "*The Thicknesses of Strata in the Counties of England and Wales*", 1916. Of great value also is a short memoir by Dr. Walcot Gibson, entitled "The Search for Coal beneath the Red Rocks of the Midland Counties", published as an Appendix to the *Summary of Progress of the Geological Survey for* 1904. Reference may also be made to the same author's "*Coal in Great Britain*" (London: Arnold, 1920) as well as to the older work of Edward Hull, *The Coalfields of Great Britain*, 3rd edition, London, 1873, and to an important paper by Messrs. Cox and Trueman "Intrajurassic Movements and the Underground Structure of the Southern Midlands", Geological Magazine, Vol. LVII, 1920, pp. 198–208. Also Cox, A. H., *Phil. Trans.*, Ser. A, vol. ccxix, 1919. App. pp. 73–139.

From the evidence supplied by these borings it is clear that the Palaeozoic floor is of varying constitution, ranging from Carboniferous to Pre-Cambrian. As to the exact constitution of this floor much will have to be said in later sections. Against this old land-surface the different subdivisions of the Mesozoic are banked up with a clearly defined but not quite regular overlap to the south-east. So far as is known, Permian strata are completely absent, and the Trias approaches its limit in several borings in Northamptonshire, dying out somewhere between Northampton and Bletchley. The Rhaetic is represented in some localities, and the Lias, which attains a considerable, but not its maximum, thickness along the outcrop, must thin out rapidly towards the south-east. As will appear in detail later, there is in most places a decided non-sequence between the Lias and the Bajocian; according to the latest views the whole of the *jurensis* zone (Upper Toarcian and Yeovillian) is absent in Oxfordshire, Northamptonshire, and Lincolnshire,[1] and the top of the Lias is usually well marked by a pebble bed.[2] The sandy facies of the Upper Lias (Cotteswold-Midford Sands) is entirely absent in the area dealt with in detail.

The variable character of the Bajocian here has long been a matter of notoriety: it is clear, however, that the conditions of Great Oolite times were somewhat more uniform, and this formation overlaps the beds below for a long way to the south-east, having been found in certain bores in the London district. The events of Upper Jurassic and Lower Cretaceous times form the chief subject of this paper, and cannot be dealt with here in summary fashion.

In the contribution to the Geologists' Association volume before cited, and in an (unpublished) essay submitted in competition for the Sedgwick Prize in the University of Cambridge, I laid much stress on the dominating influence of the Charnwood axis in the distribution of the Lower Greensand: this was in opposition to the views already put forward by Professor Kendall,[3] and my interpretation was subsequently controverted by the late Mr. Jukes-Browne.[4] However, much further study of this matter has only served to strengthen and develop my original ideas; these later and more mature conclusions are here set forth.

The thesis here developed arose primarily from an attempt to explain the peculiar relations shown in Bedfordshire and Cambridgeshire by the Jurassic and Cretaceous systems. As is well known the Mesozoic succession is here very incomplete: at Sandy the hiatus is so great that the Lower Greensand rests on the Oxford Clay, while when the base of the Cretaceous is followed away from this point in either direction higher and higher series of the Jurassic and lower divisions of the Cretaceous come in successively, till eventually in south-western England there appears to be little or no break in continuity. Hence it is obvious that the generalized structure is anticlinal, with Pre-Cretaceous denudation, and an unconformable overlap in the Lower Cretaceous.

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[1] A. M. Davies, *Handbuch der regionalen Geologie,* Band III, Abt. 1, n.d., pp. 235–9.

[2] B. Thompson, *Jour. Northants Nat. Hist. Soc.*, vol. xxi, 1921, pp. 85–98.

[3] *Final Report of Coal Commission,* p. 25.

[4] A. J. Jukes-Browne, *The Building of the British Isles,* 1911, p. 299.

According to the earlier interpretation in the memoirs above cited this anticlinal structure took the form of a single regular arch, but further consideration has shown that there must be at least two principal anticlines and possibly more, as will appear later.

But this idea can be amplified still further in the sense that along the lines of the old axes movements took place at frequent intervals during Jurassic and early Cretaceous times: most of these elevations were individually of small amplitude, but collectively they have had a considerable influence on the form of the Palaeozoic floor, and consequently on the depth at which Carboniferous rocks may be expected to occur in certain areas.

On this point Sir A. Strahan says[1]: "That the faults and folds which are observable in the Secondary rocks would be recognizable in the platform is not probable: they are, on the contrary, essentially surface phenomena and may be regarded as the efforts of a skin to adapt itself to changes in the form of an underlying body." This statement is open to criticism on two main grounds: in the first place it appears to be self-contradictory, the last clause being inconsistent with the first. For what are the "changes in form of the underlying body" but faults and folds in the platform? Secondly, it is my belief that it can be shown stratigraphically that the principal disturbances in the Secondary rocks are closely connected with old-established lines of disturbance in the Palaeozoic platform.

Since this investigation originated from a study of the peculiar stratigraphical relations shown by the Lower Cretaceous series of this area, it will be well to begin the detailed consideration of the evidence with this formation, although, as will appear later, it is believed that certain existing physiographical features can also be referred to the same set of causes. The last-named part of the subject has, however, only been taken into account since the appearance of the earlier publications already cited.

When the existing outcrops of the Lower Greensand between the Wash and Buckinghamshire are studied on the map it is soon seen that certain striking peculiarities exist. In West Norfolk the series is fairly thick, probably about 150–170 feet, and there it shows the well-known three-fold division. The Carstone is undoubtedly marine, as it contains ammonites; the Snettisham Clay is probably estuarine; while the Sandringham Sands are of uncertain origin. At any rate the last-named does not appear to be an open-sea deposit.[1]

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[1] Pres. Add., 1913, p. lxxii.

When followed southwards the Lower Greensand is for some distance very patchy and discontinuous in its outcrops, occurring only as a capping on some of the "islands" of the Fenland; one of these is at Ely and another at Upware, not shown in the Index map; there is a large expanse stretching from Stretham past Wilburton to Haddenham. Near Cottenham the outcrop begins to be continuous: for some miles it is narrow, but near Lolworth it suddenly becomes much wider: around Caxton the outcrop is about 4 miles wide, but it narrows again at Little Gransden and Waresley. At Sandy it reaches a width of about 3 miles and then almost disappears S.W. of Biggleswade. However, the width rapidly increases again, being partly covered by outliers of Gault north of Shefford. Here begins the well-known stretch of Lower Greensand country that extends past Ampthill and Woburn to come to a sudden and abrupt conclusion at Brickhill and Leighton Buzzard. The nature of the stratigraphical relations shown in the Sandy-Biggleswade area, and near Leighton Buzzard, will have to be discussed in some detail. Between the last-named place and Oxford there are only a few scattered outliers mapped as Lower Greensand, and it is by no means certain that all of these really belong to that formation: they are in any case of little importance for our present purpose, while the occurrences still farther to the west do not come into the argument at all.

It is necessary to consider next the meaning of the peculiar distribution of the Lower Greensand as above outlined. In the first place it is clear that the Norfolk facies, or at any rate the lower divisions of it, belong to a special basin of deposition; with its details we are not much concerned, but the Carstone type of sedimentation does not differ much from the normal Greensand facies, except perhaps in an abnormally high percentage of iron: where this came from is a subject of some interest in itself, but outside the scope of this paper. Around Ely, Haddenham, Wicken Fen, etc., the Greensand is obviously very thin, perhaps not more than 10 or 12 feet. It appears, however, that from Cottenham the thickness gradually increases towards the S.W., although the exact figures are not known. The Lower Greensand certainly underlies the town of Cambridge, as it has been reached by numerous wells, but it does not appear that it has ever been completely penetrated by any of these borings. A series of specimens from a deep well in Trinity College, now in the Sedgwick Museum,

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[1] It is highly regrettable that no general Memoir of the Geological Survey on the Lower Greensand has ever been published. Hence there is a lacuna in the official description of the British Mesozoic formations.

Cambridge, appear to show the presence of numerous beds of clay, one of 16 feet in thickness, in the Greensand. This feature does not seem to be known elsewhere. The Greensand is, or lately was, well seen in well-known sections at Gamlingay and Potton, though unfortunately the first-named is now much obscured. The section alongside the main line of the L. & N.E.R. at Sandy, however, is still clear and shows a considerable thickness of the sands, which are here singularly uniform in type, with a good deal of iron both in a concretionary form, and uniformly distributed. Pebble beds are absent at Sandy, though developed at Potton.

The small map in Fig. 1 gives in a generalized form the relations of the Jurassic and Cretaceous rocks around Sandy. Now in a diagrammatic map of this kind, in which no contours are shown, the narrowing of an outcrop can be explained in more than one way: not only by an actual thinning of the beds, accompanied by overlap of the next higher stratum, but also by a rise of the ground, giving a steep slope against the dip. In this particular case the last-mentioned explanation is excluded, since the ground south of Sandy is much lower than the conspicuous ridge formed by the Greensand, and constitutes the well-known alluvial flat of the Ivel valley, so largely devoted to the growing of vegetables on a large scale for the London market. If all the physiographic factors are taken into account, the only possible explanation is an actual thinning-out of the Greensand over the Jurassic anticline.

A study of the petrographical character of the sands of this series along the outcrop from Hunstanton to Leighton Buzzard has suggested, although the evidence is not perhaps quite conclusive, that the material has been poured into two distinct basins of deposition, from the N.E. and S.W. respectively, these basins being at first separated by a land ridge along the line of the Jurassic anticline.[1] This evidence is here introduced only in confirmation of the results obtained by purely stratigraphical methods.

It now remains to consider the meaning of the abrupt end of the Lower Greensand outcrop about Brickhill and Leighton Buzzard, a point not dealt with in the earlier publications cited, but believed to be of the greatest importance in a comprehensive study of the subject: it is here that the new evidence really begins, most of the foregoing being merely a recapitulation of previous work already published.

In the first place the termination of the Lower Greensand outcrop on the borders of Beds and Bucks is exactly analogous to the phenomena seen in the Ivel valley near Sandy and Biggleswade, except that in the western locality only one side of the structure is seen, the eastern limb: the western limb has either never existed, or has been completely removed by denudation.

The distance from the centre of the Sandy anticline to Leighton

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[1] R. H. Rastall, "The Mineral Composition of the Lower Greensand Series of Eastern England": Geol. Mag., Vol. LVI, 1919, p. 211.

Buzzard is about 20 miles along the strike. It would, therefore, appear that the sands were deposited in a basin between two ridges at about that distance apart. Now in the earlier publication it was suggested that the Sandy ridge was in fact due to a posthumous uplift of the Charnwood axis, in Upper Jurassic or very early Cretaceous times: it therefore remains to be considered whether any corresponding structure can be found to form a similar western limit to this basin. It is believed that such a structure does exist, and a large part of this paper will be devoted to a statement of the evidence on this point.

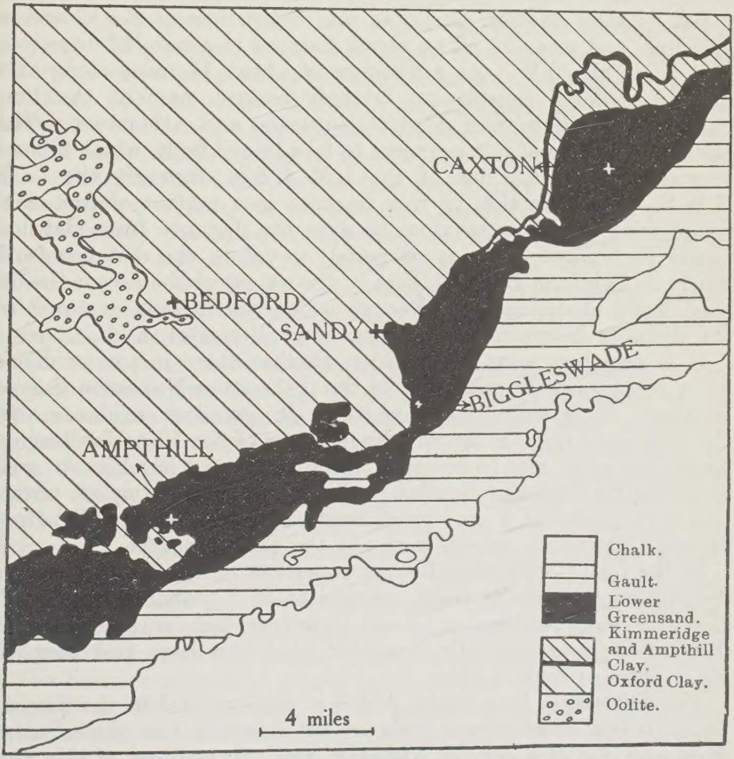

FIG. 1.—Geological map of the country round Sandy and Biggleswade. (Copied from the quarter-inch map of H.M. Geological Survey.)

The general anticlinal form of the Charnwood area is well known. From the sections and maps given by Professor Watts it is clear that the central axis lies about on the line from Bawdon Castle to Leicester, i.e. almost exactly N.W.–S.E.[1] Undoubted Charnian rocks have been struck and penetrated for some depth at Leicester and in the bore at Orton,[1] about 5 miles west of Kettering; this is exactly on the right line for the Sandy anticline, and the south-easterly extension of the Charnwood ridge may now be taken as established.

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[1] W. W. Watts, *Proc. Geol. Assoc.*, vol. xvii, 1902, pp. 373–81 and pl. xix.

This then accounts quite clearly for the local thinning of the Greensand just to the S.W. of Sandy. It now remains to consider why a similar phenomenon should occur at Leighton Buzzard, about 18 to 20 miles to the S.W. of this point.

Let us take Bawdon Castle as the central line of the Charnian anticline, and measure off an equal distance in a parallel direction, that is, to the S.W. At a distance of about 17 miles along this line we strike a conspicuous tectonic feature, namely, the Pre-Cambrian and Cambrian ridge of Nuneaton and Atherstone. The eastern boundary of this is known to be a line of fault, which follows very closely the main line of the L.M. & S.R., formerly the L. & N.W.R. The direction of this fracture is a matter of first-class significance in this connexion, because the distance from Bawdon Castle to Nuneaton is approximately equal to the distance from Sandy to Leighton Buzzard, that is, the extent of the Lower Greensand basin of deposition, when projected northwards, is equal to the distance between the Charnian and Nuneaton axes.

It is necessary next to consider whether there is any evidence for a south-easterly extension of the Atherstone-Nuneaton line of fracture. It is submitted that there is abundant evidence. In the first place there is the well-known case of the Bletchley boring, which has given rise to so much speculation, and has been so well discussed by Professor Kendall.[2] Expressed in the simplest terms, this bore passed at a very small depth (159 feet below O.D.) from Jurassic clays into igneous rocks of the Charnian type.

In the Coal Commission Report as well as in Mr. Jukes-Browne's description the granite rocks are said to be "probably boulders". However, such boulders could not have travelled far, and in recent discussions it is generally conceded that this bore just touched the surface of rock in place.

The suggestion here made, which is fundamental in the present paper, is that *these igneous rocks are not a continuation of the Charnwood axis, but of a parallel Nuneaton axis.* In support of this contention, reference may be made to the existence of a known occurrence of Pre-Cambrian volcanic rocks, the Caldecote series, in the Nuneaton area, as demonstrated by Professor Lapworth.[3]

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[1] This locality is sometimes called Harrington in the literature.

[2] P. F. Kendall, loc. cit., p. 25. A. J. Jukes-Browne, GEOL. MAG., 1889, pp. 356–61.

[3] C. Lapworth, "Sketch of the Geology of the Birmingham District": *Proc. Geol. Assoc.*, vol. xv, 1897–8, pp. 330–2. Also "The Birmingham Country, its Geology and Physiography": *Handbook of the Brit. Assoc., Birmingham Meeting*, 1913. Eastwood, Gibson and others, "The Geology of the Country around Coventry": *Mem. Geol. Surv.*, 1923, p. 7, with references.

The specimens from the Bletchley bore, some of which are preserved in the Sedgwick Museum, Cambridge, are of very poor quality, and will agree in character with the Caldecote series quite as well as with the Charnian rocks. It is quite certain that they are, at any rate, acid igneous rocks; whether volcanic or hypabyssal it is impossible to say, and a matter of no importance.

Professor Kendall, in discussing the evidence from this bore, has spoken of a ridge of Charnian rocks, towering up in Oxfordian times to a height of 2,000 feet above the general surface of the region.[1] The present writer has never been able to see how the Charnian axis could produce this effect some 20 miles west of its actual position, but the conception of a parallel and related anticline, belonging to the same fold-system, removes the difficulties inherent in this idea, and becomes, in fact, wholly consistent with it. As shown later some of the clay in this boring may be Lias.

As a matter of fact, the distance from Sandy to Leighton Buzzard is not *exactly* the same as the distance from Bawdon Castle to Nuneaton, being about 3 miles greater, but this is a small difference, and actually fold-axes rarely remain accurately parallel over a considerable distance: there is usually to be observed a spreading in one direction or the other.

The next point to be considered is the possible existence of any evidence confirming the idea of an underground extension of the Nuneaton axis towards the south-east, together with indications of posthumous movements along this line. In the first place we have the simple and uncontroverted fact of the post-Triassic date of the Nuneaton fault, which brings Trias against Cambrian and probably against Pre-Cambrian rocks, between Nuneaton and Atherstone. The general direction of this fault follows almost exactly the main line of the L.M. & S.R. as before mentioned, and if this railway is followed on the map as far south as Leighton Buzzard certain significant features are observed. At first sight the most noticeable fact is that exactly along this line each division of the Jurassic extends in a long tongue far to the south-east of its generalized line of outcrop. This feature is specially noticeable in the case of the three divisions of the Lias, the Upper Lias extending as far south as Castlethorpe. This form of outcrop can of course be produced quite simply in a uniformly dipping series by a deeply eroded dip-valley (consequent stream), and this outcrop does in fact lie partly in a valley. But here it is very easy to confuse cause and effect. The question may be raised, why does the valley lie on that line rather than anywhere else? And the answer *may* be: Because the existence of a local N.W.–S.E. anticline has brought the soft Lias clays specially near to the surface, so that the harder Middle Jurassic covering was first cut through along that line, and the stream quickly deepened its valley in the soft clay.[2] It is significant also that the Kilsby tunnel, which is nearly 500 ft. O.D., is cut through Lower Lias. This part of the V therefore is not a valley, but decidedly high ground. In a similar way, the Upper Lias is seen at the surface far to the S.E., along the line of the Charnian axis, near Bozeat and Easton Maudit, south of Wellingborough, this exposure being near the head of the valley of an obsequent stream, and therefore at a considerable height above O.D.

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[1] Kendall, loc. cit., p. 25.

[2] Cox and Trueman, Geol. Mag., Vol. LVII, 1920, p. 199.

Of evidence of a more purely stratigraphical character, derived from a detailed study of local successions, there is abundance. Mention may first be made of the broad general fact that in Northamptonshire and neighbouring counties the Lower and Middle Jurassic succession is extremely variable and in many places very incomplete.[1] It would be difficult to find elsewhere any rock-series of equal thickness showing such rapid local variations as the Bajocian and Bathonian of this region, and these variations are well known and conspicuous owing to the extensive exploitation of the iron ores of the Northampton Sand series and the quarrying of building-stones and limestones for blast-furnace use at various localities and horizons. Moreover, much detailed work by Mr. Beeby Thompson, Mr. Linsdall Richardson, the officers of the Geological Survey, and others, has shown that even the Liassic succession, and especially the Middle and Upper divisions, give evidence of a good deal of local contemporaneous disturbance.[2] In this connexion it is necessary also to take into account the evidence afforded by several deep bores in the neighbourhood of Northampton. In treating this part of the subject it will be most convenient to reverse the order hitherto adopted, and to begin with the oldest rocks.

I. *The Pre-Bajocian Rocks and the Mesozoic Overlap.*

Pre-Cambrian rocks come to the surface in Leicestershire and at Nuneaton, where also Cambrian sediments are seen. Cambrian or older rocks have also been struck in borings near Leicester, but so far as is known, Ordovician and Silurian rocks appear to be absent in this area.[3] In the Northampton borings Carboniferous rocks of peculiar type were encountered and perhaps also Devonian, overlain by Trias. From all the evidence available it is clear that the Mesozoic rocks rest on a floor of Palaeozoic and older rocks, the Permian being completely absent, and that there is a general and very decided overlap of the different members of the Mesozoic towards the S.E. The evidence for this is so well known that it need not be given in detail. At Northampton Trias rests on Carboniferous, and at Bletchley Jurassic clay rests on Pre-Cambrian: this bald statement is sufficient to prove the point. There was, however, a somewhat extensive transgression in the Great Oolite, which has been proved in bores in and around London. This was obviously merely a temporary episode of small general significance, and the distinctive feature is the regular overlap of the successive Mesozoic series against the old land to the south-east.[1]

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[1] Cox and Trueman, ibid.

[2] See numerous papers by Mr. Beeby Thompson in the *Journal of the Northampton Natural History Society*, also Cox and Trueman, loc. cit.

[3] In a subsequent section a brief reference will be made to the Lickey Hills, which lie rather outside the region here dealt with, but will form an important factor in the later argument.

From the small thickness of the Trias in the Northampton bores,[2] and from its lithological character, it is clear that this formation must thin out a short distance to the south-east of this town.

Apart from the persistence of old land-surfaces in the Mendips and in South Wales the Lower Lias is characterized by remarkable uniformity of conditions, with an abundant supply of sediment, at first calcareous and then more muddy. Over Northamptonshire the average thickness of the Lower Lias may be taken as about 470–500 feet, and its general character indicates a period of tectonic quiescence; it seems clear that the general shore-line then ran more or less uniformly from S.W. to N.E. probably only a few miles from the line of the present Chalk escarpment. It seems to be generally accepted that the Lower Lias is largely made up of debris from the Carboniferous limestone, but this by no means proves, as often seems to be assumed, that the material must have come from the N.W. There probably was also a large area of Lower Carboniferous undergoing denudation over the old Southern plateau, as there is every reason to believe that the Mendip and Belgian areas were once continuous, and in point of fact Carboniferous limestone has been proved in Kent.

The Middle Lias of the same area is a much thinner formation, giving evidence of a shallow sea. It is sandy and calcareous rather than argillaceous, while both around Banbury and in Leicestershire the upper part, usually known as the Marlstone, contains valuable beds of iron-ore. The absence of the iron-bearing facies to the south-west of Northampton is probably of some significance in the argument. The genesis of oolitic iron ores is one of the mysteries of geology, and if the iron content of the ore is primary, as now advocated by certain writers,[3] it indicates very peculiar conditions of deposition. This subject cannot, however, be profitably discussed here. According to Mr. Beeby Thompson [1] the average thickness of the Middle Lias of Northamptonshire may be taken as about 51 feet, although other authors attribute to it a somewhat greater thickness, even up to 100 feet, a figure indeed given by Mr. Thompson himself in a later publication.[2]

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[1] In a remarkable paper Mr. E. Hull proved clearly the thinning of the Jurassic rocks towards the S.E., but missed the obvious inference of an overlap. However, this paper contains a wonderful forecast of the character of the Palaeozoic floor, considering the scanty data then available. (*Q.J.G.S.*, vol. xvi, 1860, pp. 73–81.) This paper should be ranked with Godwin-Austen's great memoir on the area south of the Thames, published four years earlier. Ibid., vol. xii, 1856.

[2] Full details of these bores will be found in the Coal Commission Report, and in Sir A. Strahan's Presidential Address to the Geological Society, 1913, "Thicknesses of Strata": *Mem. Geol. Surv.*, 1916, pp. 6–7. See also Beeby Thompson in *Geology in the Field*, p. 452, and H. J. Eunson, *Q.J.G.S.*, vol. xl, 1884, p. 482.

[3] See for example, L. Cayeux, *Les Minerais de Fer oolithiques de France*, fasc. i, 1909, and fasc. ii, 1922. A. O. Hayes, *The Wabana Ores of Newfoundland*, 1915.

It is quite clear that here the thickness is much less than in, e.g., Dorsetshire or Lincolnshire. This is to be referred to a differential uplift, since the rocks were obviously formed in shallower water in the central area, with a greater abundance of calcareous organisms, as shown by the character and fauna of the Marlstone rock-bed, while the lowest zone of the Upper Lias is possibly absent. The influence of the south-eastern shore-line was obviously making itself felt in the character of the sediment deposited, and the area seems to have been raised above the general mud-line into the zone of sands and shell banks.

The following table gives the thicknesses of the Upper Lias as measured at various localities in Northamptonshire; the figures are derived from the various publications already frequently cited :

	ft.		ft.
Brackley	109	Hartwell	112
Brington	180	Kettering	163
Burton Latimer	182	Kingsthorpe	183
Desborough	212	Northampton	155
Duston	190	Towcester	119
Finedon	130		

It will be seen that the greatest recorded thickness is 212 feet at Desborough, N.W. of Kettering. However, there is some doubt as to the interpretation of this bore, and it has been suggested that the excessive thickness may be due to penetration of an inclined fault plane. Apart from this, however, the thicknesses vary within wide limits from 190 feet at Duston and 183 feet at Kingsthorpe to 119 feet at Towcester and 109 feet at Brackley, the intermediate localities showing little or no regularity of arrangement. Furthermore, there is a difference of 52 feet between Finedon and Burton Latimer, which are only 2 miles apart. It seems pretty clear that these variations in thickness cannot be original: it is generally recognized that there are considerable gaps in the succession and that the Northampton Sand series commonly rests on the Lias with a pebble-bed at its base, this pebble-bed containing abundant Upper Lias fossils.[3] Mr. Beeby Thompson has also described folding in the Upper Lias before the deposition of the Northampton Sand series. Now it is known that under the conditions indicated by these phenomena there are often local wash-outs of considerable depth but of very limited lateral extension; as, for example, occurs at this same horizon in Rosedale and Bilsdale in N.E. Yorkshire. In the last-named dale the base of the Dogger for a mile or so is within 30 or 40 feet of the Jet Rock (*serpentinus* zone). This may indicate the removal of as much as 160 feet of strata before the deposition of the Dogger.[1] It is very possible that similar relations exist in Northamptonshire.

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[1] B. Thompson, *The Middle Lias of Northamptonshire*, 1888, p. 7.

[2] B. Thompson, "The Water Supply of Beds and Northants": *Mem. Geol. Surv.*, 1909, p. 5.

[3] B. Thompson, *Jour. Northants Nat. Hist. Soc.*, vol. xxi, 1923, pp. 85–98.

The arenaceous shallow water facies of sedimentation represented by the Midford and Cotteswold Sands does not occur in Northamptonshire. The Cotteswold Sands are now generally considered to belong to the uppermost part of the *bifrons* zone, these sands coming in at successively lower horizons from Dorset to the Cotteswolds.[2] In Oxfordshire, Northamptonshire, Rutland, and Lincoln it is believed that the whole of the *jurensis* zone is absent, the ironstone series of the Northampton Sands resting directly on clays of the *bifrons-communis* zone. This is a fact of the utmost importance for the argument here brought forward, and it may in fact be regarded as the earliest of the phenomena to be discussed in detail, as the forerunner of later events.

From the present point of view the question is not so much the exact palaeontological horizons at which this gap begins and ends, as whether the missing strata were deposited and then removed, or whether sedimentation entirely ceased towards the end of Upper Lias time, and if so, why. But in either case it is obvious that there must have been some disturbance to lead to this state of affairs, and its exact date is of much less interest than its nature and cause.

With regard to the hypothesis of complete failure of deposition it is of interest to note that in the Cotteswolds the whole of the *jurensis* zone is said to be condensed into the 3 feet of the Cephalopoda Bed, showing that very little deposit of inorganic matter was taking place even there: this must mean a very shallow sea, while near Bath and in Dorset the same thing happened in the *bifrons-communis* zone *below* the Midford Sands of that area,[3] thus indicating unstable conditions at an even earlier date.

The general inference to be drawn is, an unstable condition of the crust over a wide area, extending episodically and locally throughout Upper Liassic time and culminating towards its latest stages.

Since the Upper Lias of Northamptonshire is on the whole a fairly uniform clay-formation it seems more probable that the variations in thickness and the absence of the *jurensis* zone are due to subsequent removal of deposits rather than to non-deposition, which must necessarily introduce variations of lithological characters.

The facts here detailed seem to suggest that at the end of Lias times there was a general uplift of the whole region, leading to the formation of a plane of marine denudation, a sort of submarine peneplain, forming a base or substratum for the accumulation of the special deposits of the Bajocian, which may perhaps be more satisfactorily regarded as something of the nature of a delta or lagoon facies, rather than as truly estuarine.

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[1] R. H. Rastall, *Q.J.G.S.*, vol. lxi, 1905, p. 456.

[2] *Handbuch der regionalen Geologie*, Band III, i, p. 235.

[3] Ibid.

The study of the stratigraphy of this period here suggests a more or less general uplift of a considerable area, rather than fold-movements along the lines of the ancient axes, a phase of epeirogenesis rather than orogenesis. In any case the geography of the Middle Jurassic of Northamptonshire must have been very complicated, as shown by the exceedingly rapid alternations of lithological types, both in time and space. At any rate it is significant that the Lincolnshire limestone, clearly an open sea formation, comes to an end not far from Kettering, while the calcareous facies begins again in Gloucestershire after a long gap extending over the disturbed area.

Here another point of interest presents itself. It seems clear that the special conditions of the Northampton Sand series did not extend far towards the south-east; this formation did not overlap the Lias in this direction, as shown by certain well-sections at Olney, near Bedford. Here Upper Bathonian strata appear to rest directly on Upper Lias Clays. This fact may be taken as evidence in confirmation of the littoral lagoon origin of the Bajocian and lower Bathonian (Estuarine) series, which probably extended as a comparatively narrow fringe along a south-western shore-line: it is in fact possible that the Northampton ironstone and estuarine series never had a N.W.–S.E. extension much wider than that now existing.[1]

II. *The Middle Jurassic.*

After the events narrated in the last section a period of sedimentation again set in over the Midland Counties, but it was sedimentation of a very peculiar and irregular kind. It is hardly too much to say that in no other known instance, in this country at any rate, is there to be found such rapid variation in character and thicknesses of strata, both horizontally and vertically, as between the Upper Lias and the Cornbrash of Northamptonshire and the adjoining counties. It is noteworthy, though perhaps as yet not explicable, that it is precisely in this highly disturbed area that the Northampton Sand Series carries such large and important deposits of iron ore: one consequence of this is that good sections are frequent and the details are well known. From all this welter of variable sequences, however, one fact emerges clearly, namely, that most of these strata are of "estuarine" or freshwater origin. In most descriptions of so-called estuarine strata it is not very clear what is really meant;

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[1] This argument is summarized very briefly from an unpublished essay submitted by the author in competition for the Sedgwick Prize in the University of Cambridge, 1912.

whether the writers had in mind truly estuarine deposits such as are now being formed in the mouths of rivers like the Thames, Dee, and Severn, or rather deltaic accumulations. Truly estuarine deposits of the first type would normally contain numbers of marine shells and all vegetation would be drifted. But strata without marine shells and with indications of plants in the position of growth suggest deltas, and it is to this type that the beds in question largely belong. Strictly they should be called deltaic and not estuarine. There are, however, intercalations of marine episodes of calcareous sedimentation such as the Lincolnshire Limestone and the Great Oolite Limestone, the former being of very considerable thickness and importance in Rutland and Lincolnshire though very poorly represented in north Yorkshire. Towards the south-west it dies out near Kettering. The Bathonian limestones have been locally quarried as flux for the iron works, and in former times also to a considerable extent as building stones, e.g. the Gayhurst stone from the neighbourhood of Newport Pagnell, which is found in the older buildings in Cambridge.

The *aalensis* zone[1] is considered to be absent in Northamptonshire, and the ironstone beds are referred by Mr. Linsdall Richardson to the *scissum* zone. Mr. Beeby Thompson objects to this correlation on what seems the very reasonable ground that this ammonite has never been found in the ironstone proper, and only once (possibly) in the variable beds above. At any rate the Northampton Sand Series and the Lower Estuarine series above represent some part of the old "*murchisonae* zone". In Northamptonshire also there is clear evidence of an unconformity between the Lower and Upper Estuarine series, where the Lincolnshire Limestone is absent. We are here on very controversial ground, but the main point seems clear, that there was an unusually considerable disturbance of a generally and episodically disturbed area at about the middle of Bajocian time. That is all that it is here sought to establish in connexion with the instability of axes of folding.

There seems to be some doubt as to what is actually represented by the Cornbrash of this area. This facies is certainly present: it is separately mapped by the Geological Survey and plays a very important part in capping certain plateau-like areas near Thrapston and Kettering. At the surface it is one of the most conspicuous of the local formations. But its zonal correlation is a somewhat difficult matter. In point of fact the Cornbrash is a facies-formation and therefore necessarily of different ages in different areas; towards the north it appears to be later than in the south-west of England, and its representative in North Yorkshire probably belongs to the Upper Jurassic. (Oxfordian in the old wide sense; Callovian of the Continental classification.) In Northamptonshire, at any rate, it appears to represent a phase of some temporary stability over a fairly wide area.

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[1] Zonal names are here used in the sense employed in the *Handbuch der regionalen Geologie.*

III. *Upper Jurassic.*

In the earlier descriptions of the Bletchley boring, including the *Report of the Coal Commission*, 1905, and Sir A. Strahan's *Presidential Address*, 1913, it was assumed that the whole of the clays there encountered down to 419 feet from the surface, belonged to the Oxfordian, part being referred to the Kelloways facies.[1] However, in a paper dealing mainly with the Calvert borings,[2] Dr. A. M. Davies has suggested that the lower portion of the strata passed through at Bletchley may belong to the Forest Marble and the Lias. The following correlation is suggested between the Bletchley and Calvert borings :

	Calvert.		*Bletchley.*	
	ft.	in.	ft.	in.
Oxford Clay . . .	93	3	192	0
Forest Marble . . .	38	9	33	0
Great Oolite . . .	67	0	absent	
Lias (Charmouthian) . .	240	6	185	0

It is only fair to say that Professor Kendall also expressed his opinion that rocks older than the Oxfordian might be present. These figures make the depth of the Palaeozoic floor to be about — 150 feet O.D. If there really is Lower Lias here at this small depth it necessarily shows an uplift somewhere between Liassic and Oxfordian times. It was suggested by Jukes-Browne that the igneous rock occurred only as boulders in the Kelloways rock, but it is now generally admitted that these masses of quartz-porphyry must have been either actually in place or so nearly so as to allow us to assume that the Palaeozoic floor lies within a foot or two of this depth, which is extraordinarily small, as compared with e.g. Little Missenden and the London area. Here the crest of the Nuneaton anticline is higher than that of the Charnwood anticline further east, at Orton and Ware. Unfortunately, no data exist for estimating the depth to the old rocks at Sandy.

The Kelloways facies of the Lower Oxfordian is not seen at the surface in this area, while the remainder of the Jurassic, so far as it exists, appears to be exclusively marine, and apparently laid down in an area of considerable stability : it is essentially a clay formation, the only notable exception being the coral reef of Upware, near Cambridge. The Kimmeridge Clay is more shaly than the beds below, but even the highest division, as exposed in the Roswell pit at Ely, does not suggest particularly shallow water conditions. Hence it may be inferred that still higher strata were once present and have been removed. It is, however, notable that the Kimmeridgian is particularly thin in Cambridgeshire, the lower division and part of the upper together amounting to not much over 100 feet. Also it is clear that the thickness assigned to the Ampthill Clay by most writers is greatly exaggerated: it probably does not average more than 15–20 feet.[1] However, from the data available it is not possible to draw any definite conclusions as to the meaning of these facts, and exposures are rare in the Corallian and Kimmeridgian strata. The Elsworth Rock alone is suggestive of temporary shallow water conditions, but its actual extent is not very well known.[2] The peculiar strata apparently encountered in the Norfolk oil-shale borings and sinkings will not be considered here.

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[1] See also Jukes-Browne, Geol. Mag., 1889, pp. 356–7.

[2] A. M. Davies and J. Pringle, " On Two Deep Borings at Calvert Station " : *Quart. Jour. Geol. Soc.*, vol. lxix, 1913, pp. 308–40, especially p. 332. There appears to be a discrepancy of 9 feet in the depth of this bore, as given in the Coal Commission Report and in the original engineer's record quoted in this paper.

With regard to the south-easterly extension of the Upper Jurassic rocks data are unfortunately very scanty. In the deep bores of the London district it is quite clear that they are entirely absent, no formation between the Great Oolite and the Lower Greensand having been identified. The only evidence bearing on this point is that obtained from a boring at Saffron Walden, and the records from this are regrettably vague.[3] The record of this bore, as generally quoted, is as follows: "total depth, 1,004 feet; height of surface above O.D., about 200 feet; Chalk, 275 feet; Chalk Marl, Gault, Lower Greensand, Kimmeridge Clay, and Oxford Clay to 729 feet." From these statements it is only possible to conclude that here Upper Jurassic strata of some kind extend considerably to the south-east of their general presumed line of termination. The depth to the Palaeozoic floor is unknown, but if this bore is plotted in its proper relation to those at Turnford, Ware, and Culford, it is clear that the line showing the overlap of the Cretaceous over the Jurassic must here make a very considerable bend; in fact, it is an indication of the existence of a narrow gulf in Upper Jurassic times, or what comes to the same thing, a depression in the old Palaeozoic plateau. As a very rough estimate we may suppose that the Cretaceous rocks below the Chalk amount to about 250 feet (Gault 100 feet, Lower Greensand 150 feet). This leaves about 480 feet for Jurassic clays plus an unknown depth to the floor. Nothing like this exists in any other known boring in the south-eastern counties. Even at Lowestoft, where Palaeozoic rocks were struck at 1,615 feet O.D., these were directly overlain by Lower Greensand.[1] Therefore, in north-western Essex, between the Charnwood axis and the old rocks of Culford, there must have been a long overlap of Jurassic rocks in a tectonic depression.

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[1] Stratigraphical details as to the Upper Jurassic rocks of Cambridgeshire will be found in the author's contribution to *Geology in the Field*, already cited, with references to the literature. See also especially Roberts, *The Jurassic Rocks of the Neighbourhood of Cambridge*, Cambridge University Press, 1892. Morley Davies, Geol. Mag., 1916, p. 395.

[2] Wedd, *Quart. Jour. Geol. Soc.*, vol. liv, 1898, pp. 601–18, and vol. lvii, 1901, pp. 73–83.

[3] *Coal Commission Report*, p. 43. Strahan, Pres. Add., p. xc. "Geology of N.W. Essex": *Mem. Geol. Survey*, 1878, p. 79.

From the facts detailed in the preceding sections, and from the general literature of the Jurassic strata of the Midlands, which is fairly extensive, the general conclusion may be drawn that the Middle Jurassic and the latest stages of the system were laid down in an area of frequent and well-marked disturbance of a tectonic nature. During the Lower Lias there seems to have been a general quiescence or perhaps rather a general subsidence of the area, but in the Middle Lias there are signs of a shallowing of the water with local discordances. The Upper Lias indicates increasing instability, which culminated in the extremely variable conditions of the Bajocian and Bathonian. The Great Oolite shows a long overlap to the south, but this movement of depression seems to have been soon arrested, and the absence of the Kelloways facies shows fairly deep water in Oxfordian times. But in the highest Jurassic a great disturbance clearly set in : if Portland beds were ever deposited they were soon swept away, and a great discordance resulted from elevation of the Charnoid axes. In fact, it was not till the beginning of the almost world-wide Cenomanian transgression that anything like a general deposition of purely marine strata began again, and even this was interrupted by the local episode of the Cambridge Greensand. The Cenomanian transgression was obviously due to causes of a higher scale of importance than those that affected the Jurassic strata ; that is to say, it was probably epeirogenic rather than orogenic, and so need not be discussed further here, since it belongs to an altogether different order of phenomena. These intra-Jurassic disturbances may be correlated with the Cimmerian phase of crust-disturbance in central Germany, in which in many areas a N.W.–S.E. directrix is dominant.[2] The author hopes in a later publication to pursue this subject further.

Although deep bores reaching down to the Palaeozoic floor are by no means numerous in the area here dealt with and are specially scanty in the eastern half of it, still a certain number do exist, while in East Kent they are of course quite numerous, though in some cases the details are not yet available. Most of these bores are summarized in the publications so frequently quoted. From this information and from the results of one or two later bores, especially Calvert and Little Missenden, an attempt has been made to construct a map indicating the overlap of the Mesozoic formations over the old London plateau. The principle of this map (Fig. 2) is perhaps in need of a little explanation, as it is of a somewhat unusual character. It is not a map of the Palaeozoic floor, but of the under side of the Mesozoic cover. Each division of the map shows the area within which the formation in question rests directly

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[1] Strahan, loc. cit., p. lxxxviii.

[2] H. Stille, *Geol. Rundschau*, Bd. IV, 1913, pp. 563–83.

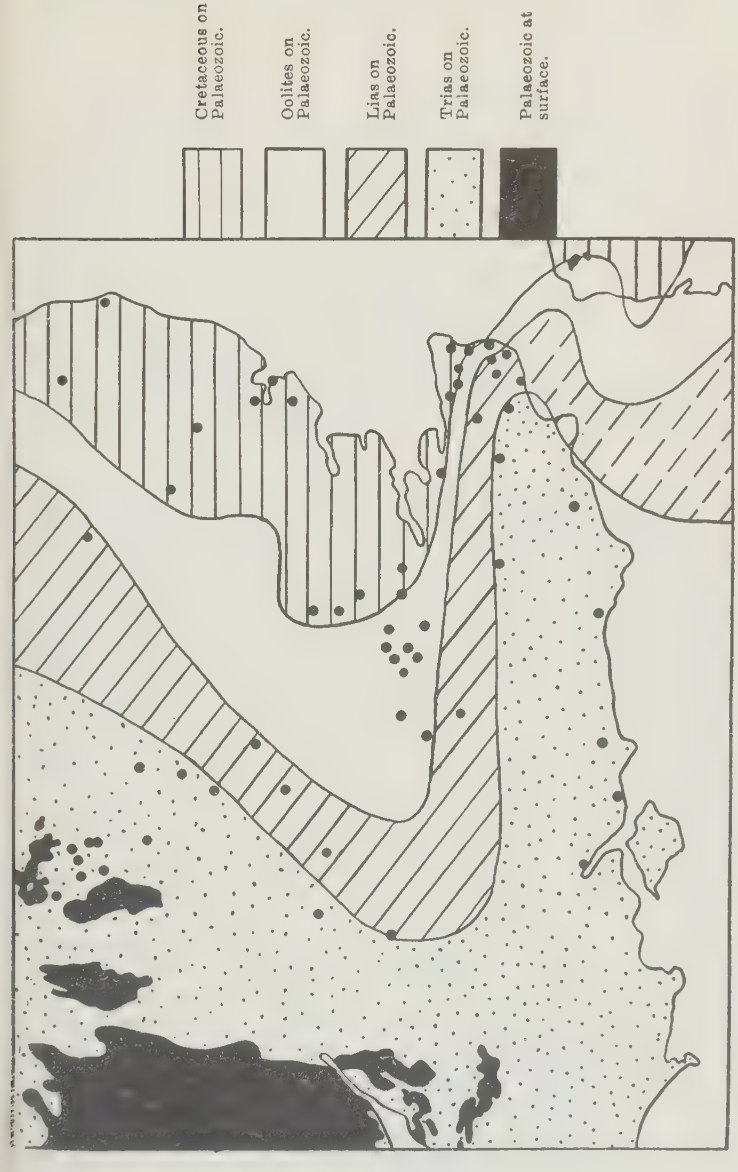

FIG. 2.—Map of the lower surface of the Mesozoic rocks of the south-east of England. Black spots are borings.

on the Palaeozoic floor, so far as can be ascertained from the available data. The lines are obviously highly generalized and there is necessarily much extrapolation. Further, the scale is so small and the boundaries so much generalized that the map cannot be expected to show the inequalities of elevation that must exist in the Palaeozoic floor, especially along the lines of the Charnoid axes. The black areas show outcrops at the surface of Carboniferous and older rocks. Actual depths are entirely disregarded since these are evidently controlled to a great extent by Tertiary movements, and the map is meant to show rather the state of affairs in late Mesozoic times. It may be compared with map C given by Sir A. Strahan.[1] The area south of the Thames is inserted only for the sake of completeness and is copied mainly from the publications of the Geological Survey; the outline of the Trias basin is taken chiefly from a map given by Jukes-Browne,[2] while most of the lines in the extreme S.E. corner, with which this paper is not really concerned, are taken from Mr. Forster Brown's paper in the *Proceedings of the Institute of Civil Engineers*, vol. ccxv, 1923, pp. 27–65.

At this point mention may be made of a fact of some interest, as indicating a possible renewal of activity in the Charnwood axis at a very late geological date. It is generally agreed that the river system of central England was initiated in Miocene times. Now in a tract of a few square miles west of Kettering there exists what appears to be a very perfect example of consequent drainage on a small scale, with a watershed running N.W.–S.E. and primary streams flowing off this at right angles. The floors of these valleys are composed of Upper Lias and the whole thing comes out very clearly in Sheet 52, N.W., Old Series, of the Geological Survey 1 in. maps. This watershed happens to lie exactly on the line of the Charnwood axis.

A structure of this kind could no doubt be explained in various ways, and no stress would be laid upon it but for one remarkable fact, namely, that within a mile or less of this watershed lies the Orton boring, where Charnian rocks were actually struck below Trias at only – 341 feet O.D. This fact is too remarkable to be disregarded. It might be suggested at first sight that this idea is directly opposed to the assumption previously made that rivers have cut deeply into N.W.–S.E. anticlines along their axes (see p. 20). But no real contradiction is involved. It is a question of relative age. The other anticlines are supposed to be of Mesozoic age and there has been time for the rivers to cut far down through the comparatively hard Middle Jurassic strata into the soft Lias below, whereas in the instance here cited, where the uplift is Tertiary, denudation has failed to penetrate the limestones (chiefly Cornbrash) on the crest of the ridge, the anticlinal form still persisting as a surface feature, like the watershed south of the Yorkshire Esk.

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[1] Loc. cit., 1913, pl. C, facing p. lxxvii.

[2] Jukes-Browne, *Building of the British Isles*, fig. 37, facing p. 248.

PART II

From the somewhat minute discussion of the stratigraphical details of a limited area, as set forth in the preceding sections, we must now turn to a more generalized study of the tectonics of the Southern Midlands regarded as a whole. An attempt has already been made to demonstrate the existence of at least two well-marked axes of recurrent elevation, that is, of posthumous movement along old-established trend-lines: these are the Charnwood and the Nuneaton axes, which possess a N.W.–S.E. strike, probably dating from later Pre-Cambrian times. It is hoped to show that the influence of similar and parallel directrices can be traced in other tectonic features of the Midlands, in most cases in combination with structural lines developed at a later period.

In their general treatment of the development of the Midland Coalfields in the Final Report of the Coal Commission (1905) Professor Lapworth and Professor Kendall brought out the fan-like form assumed by the structural lines controlling the lie of the Palaeozoic rocks, at any rate in so far as the visible coalfields of the northern Midlands are concerned, and this feature was emphasized by Sir A. Strahan in his Presidential Address to Section C of the British Association at Cambridge 1904.[1] The aim of the present paper is to show that the tectonics of the portion of the Southern Midlands now under an uninterrupted cover of Mesozoic strata, can be elucidated by the conception of the superposition of a post-Carboniferous fan on an underlying structure composed essentially of folds of N.W.–S.E. (Charnoid) trend. To use a homely analogy, the process may be likened to the bending of a sheet of corrugated iron under the influence of external pressure. In this case the external pressure is applied obliquely to the corrugations.

In the north of England, the dominant feature is the Pennine uplift, whose main axis appears to have a N.–S. direction. But even in Derbyshire, there are complications, as shown by the "oil anticlines" of the Chesterfield area, the faults of the coalfield, and still more distinctly by the dome-like inliers of Ashover and Crich. Here the Charnoid trend of the domes is obvious.[2] The influence of the Charnoid directrix is here so clear that Sir Aubrey Strahan has indicated that in his view the Charnwood anticline is to be regarded as the direct continuation of the main Pennine anticline.[3] But this is evidently not the whole story, since there are other lines of equal structural importance not there taken into account.

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[1] See also Fearnsides, *Trans. Inst. Min. Eng.*, vol. li, pt. iii, 1916, p. 107.

[2] See 1 inch map of the Geological Survey, N.S., Sheet 112.

[3] Pres. Add. to Sect. C, Brit. Assoc., Cambridge, 1904. Report, pl. viii.

The following list shows in tabular form the trend-lines and outcrops of older rocks in the Midland area :—

A.	Charnwood axis	N.W.–S.E.
B.	Nuneaton axis	N.W.–S.E.
C.	Sedgley–Lickey line	N.N.W.–S.S.E.
D.	Western margin of Warwickshire Coalfield	N.–S.
E.	Eastern margin of S. Staffs Coalfield	E. of N.–W. of S.
F.	Western margin of ,, ,,	N.N.E.–S.S.W.
G.	Stretton fault	N.N.E.–S.S.W.
H.	Line of Abberley and Malvern Hills	N.–S.
I.	Woolhope and May Hill inliers	N.W.–S.E.

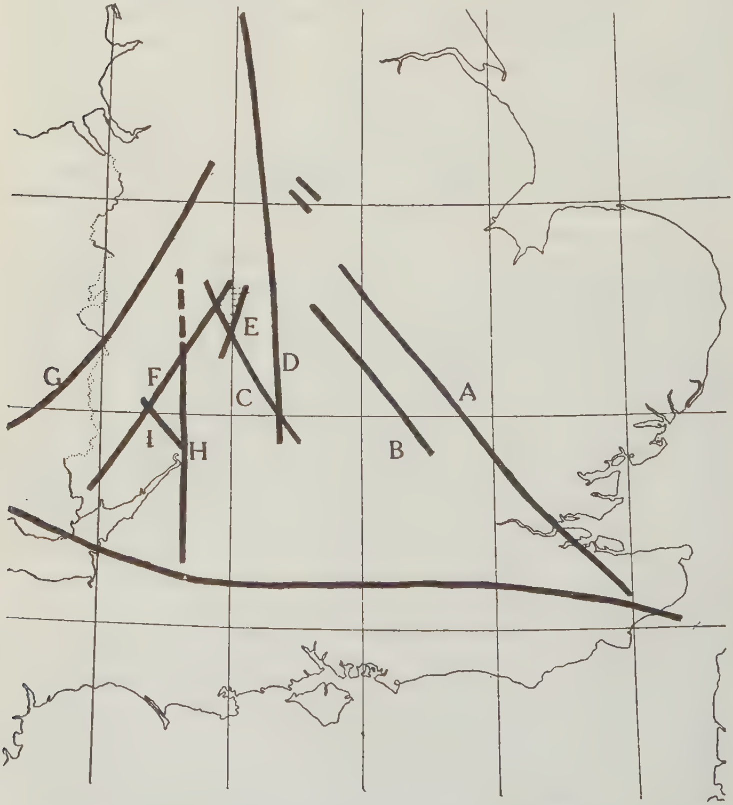

FIG. 3.—Map of the trend-lines of the Midlands.

Further south the influence of the Armorican E.–W. folds is dominant, both in the distribution of the Palaeozoic and of the later rocks.[1] These will not be here considered.

With regard to A and B of this table enough has already been said : it may be noted here, however, that Dr. H. T. Brown has

[1] For a summary and diagram of these, see Jukes-Browne, *Building of the British Isles*, chap. vii, and map, pp. 186–7.

demonstrated pretty clearly the existence in Leicestershire of a subsidiary parallel anticline between those of Charnwood and Nuneaton at a comparatively small depth.[1]

C. *The Sedgley-Lickey line.*

This heading refers to the well-known inliers of Silurian rocks in the S. Staffs. coalfield and the outcrops of Pre-Cambrian and Silurian rocks of the Lickey Hills, Barnt Green and Rubery. As shown by Professor Lapworth,[2] three of these Silurian outcrops of the coalfield, those of Sedgley, Wren's Nest, and Dudley, though elongated from north to south, lie along a line which when continued hits the Lickey Hills, the strike being N.N.W.–S.S.E. This line when continued passes through the Vale of Moreton, an area which will shortly be referred to again, as it also lies on another tectonic line of importance; the treatment of this feature may therefore be postponed. As a matter of fact, the continuation of this line exactly hits the Goring Gap, but this may be purely fortuitous, and no stress is laid on it.

D. *The Western Margin of the Warwickshire Coalfield.*

From the present point of view the significance of this line arises from the fact that it runs almost exactly N.–S. and is a direct continuation of the main axis of the Pennine anticlinorium as developed in Derbyshire. Furthermore, towards its northern end is found the small Cambrian outcrop of Dosthill,[3] while to the south it is traceable into the Vale of Moreton, an area which is universally admitted to be of anticlinal structure[4]; the upper part of the Inferior Oolite here rests directly on the clays of the Upper Lias, which is not more than about 40 feet thick.[5] Hence there is clear evidence of intra-Jurassic disturbance, as well as of anticlinal uplift at a later date.

Towards its southern end the Lias outcrop of the Vale of Moreton is split into two branches: the eastern one, which forms rather low ground, is followed by the Great Western Railway through Kingham (formerly Chipping Norton Junction). The other branch extends southwards past Bourton-on-the-Water, and it is significant that this long tongue of Lower Lias, lying exactly on the continuation of the Pennine axis, occupies fairly high ground at a little over 400 feet O.D. The suggestion here made is that this peculiar form of outcrop is due to the crossing of the Pennine and Lickey axes. In a boring at Batsford, near Moreton-in-the-Marsh, Silurian rocks were struck at 651 feet O.D. below about 520 feet of Coal-measures.[1]

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[1] H. T. Brown, *Quart. Jour. Geol. Soc.*, vol. xlv, 1889, pp. 1–38, and especially pp. 29–35.

[2] *The Birmingham Country*, Handbook Brit. Assoc., Birmingham, 1913, reprinted by Cornish Brothers, Birmingham, 1913. *Proc. Geol. Assoc.*, vol. xv, 1897–8, pp. 328 and 350.

[3] A. Strahan, Geol. Mag., 1886, pp. 540–57. G. Barrow and others, "The Geology of the Country around Lichfield": *Mem. Geol. Surv.*, 1919, p. 7. R. D. Vernon, *Quart. Jour. Geol. Soc.*, vol. lxviii, 1912, pp. 587–638, and pl. lxi.

[4] Cox and Trueman, Geol. Mag., Vol. LVII, 1920, pp. 198–208. Buckman, *Quart. Jour. Geol. Soc.*, vol. lix, 1903, p. 449.

[5] A. J. Jukes-Browne, *The Building of the British Isles*, 1911, p. 268. *Handb. regionalen Geol.*, 1917, p. 235. H. B. Woodward, "The Lias of England and Wales": *Mem. Geol. Surv.*, 1893, p. 268.

E. *The Eastern Margin of the S. Staffs. Coalfield.*

This is a somewhat irregular line partly made up of a series of faults.[2] However, its general trend runs slightly E. of N. and W. of S. It is thus quite conformable to the fan-structure. The most noticeable fact about it is that its continuation cuts the Sedgley-Lickey-Moreton line in the middle of the Lickey inlier, thus indicating that the last named may be an area of super-elevation in Haug's sense.

F. *The Western Margin of the S. Staffs. Coalfield.*

In a similar way the north-western margin of this coalfield is formed by a series of faults having a general trend a few degrees east of north and west of south. This line is of importance, because when continued it cuts the Abberley Hills, the Woolhope and Usk inliers, and the Silurian rocks of Cardiff, thus forming the eastern limit of the South Wales coalfield.

G. *The Stretton Fault.*

This great fault and its continuations form one of the dominant features of the tectonics of western England and Wales. It can be traced probably as a continuous line of dislocation and disturbance from near Macclesfield as far as New Radnor and its probable further continuation can be followed in a narrow outcrop of Silurian rocks nearly as far as Brecknock. It forms the western boundary of the North Staffordshire coalfield, bringing Trias against Lower Coal-measures. In Shropshire it produces marked effects on the stratigraphy, which need not here be enumerated. The general direction is about N.N.E. and S.S.W., with slight local deviations: the southern portion runs more nearly N.E.–S.W. This is clearly a Caledonian direction, and this dislocation may be taken as the south-eastern limit of the Caledonian fold-system in the Midlands.

H. *The Malvern Ridge.*

One of the conspicuous features of the geological map of the western Midlands is a N.–S. line which is traceable from the neighbourhood of Market Drayton to the Mendips, culminating in the Malvern range, where Pre-Cambrian gneisses of Archaean type are raised to a considerable height. As a matter of fact almost the whole of this great stretch of disturbed country can be seen from the top of the Worcestershire Beacon.[3] Along parts of this line a dominant westerly component in the direction of movement is obvious, leading in places to a decided overthrust towards the west. This can be seen on the east side of the Forest of Wyre coalfield, and is very strongly marked in the Malvern and Abberley Hills.[1]

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[1] *Coal Commission Report*, 1905, pp. 16 and 36. Strahan, loc. cit., p. lxxxiv.

[2] W. Gibson, *Coal in Great Britain*, 1920, fig. 41. p. 211.

[3] The writer has seen the Mendips and the Wrekin from this point on a very clear day in 1916.

The chief component parts of this system are: the eastern margin of the Coalbrookdale and Forest of Wyre coalfields, the Abberley Hills, the Malvern range, the May Hill and the Tortworth inliers, and a line of elevation running to the east of the Radstock coalfield. When plotted on a map this axis of elevation is seen to be exactly parallel to the Pennine axis. It must be admitted that to a considerable extent it destroys the symmetry of the fan, but it is evidently an important structure of early origin which has undergone many movements, the last being clearly post-Triassic.

I. *Woolhope and May Hill.*

The inliers of Woolhope and May Hill are dome-like masses of Silurian rocks rising up through the Old Red Sandstone, obviously formed by the intersection of anticlinal axes. The point of greatest interest in the present connexion is the conspicuous N.W.–S.E. strike of the principal axis of the resulting structures, showing that the old Charnoid trend was dominant over the later movements, even so far to the west as this. It would be difficult or impossible to find better examples of Haug's "areas of superelevation". This line was obviously the locus of the two epicentres of the Hereford earthquake of 17th December, 1896.[2]

Among minor structures which must also be taken into account in the present discussion are the following: in Derbyshire a Charnoid trend is distinctly marked in the limestone inliers of Ashover and Crich, which are typical domes, and also in the very abundant faults of the Derbyshire coalfield. In the same area there are also the "oil anticlines" of the Chesterfield district. There is further a very strong suggestion of a Charnoid influence in the dominant faults of the Potteries coalfield (Apedale and Newcastle faults). The first named is described as essentially a monoclinal structure, an early stage in the formation of an overthrust from the east: these faults are approximately parallel to the Lickey line. The well-known faults of the district between Manchester and Wigan also have a Charnoid direction, some of them being of large throw. Moreover, the vast majority of the faults traversing both the Lancashire and the Yorkshire-Derbyshire coalfields, which are very numerous, show either a Charnian or a Caledonian trend, as shown by a striking figure given by Messrs. Kendall and Wroot.[3] There are also indications of the same influence much further north in the strike of the Ingletonian and Lower Palaeozoic rocks of Chapel-le-Dale and Horton-in-Ribblesdale. It may also be mentioned here that the "Cleat" in coal seams in Lancashire and Yorkshire shows a dominantly Charnoid trend.[1]

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[1] Strahan, *Rep. Brit. Assoc.*, 1904, p. 536. Groom, *Quart. Jour. Geol. Soc.*, vol. lvi, pp. 138–97.

[2] C. Davison, *A History of British Earthquakes*, Cambridge, 1894, pp. 249–56.

[3] *Geology of Yorkshire*, 1924, figure on p. 243.

In the same category may be placed certain features of the Jurassic outcrop, namely the long tongues of Lower Jurassic rocks extending far to the S.E. of the general line of strike; for example, the Upper Lias above Bedford, the Upper Lias at Castlethorpe and in the Cherwell valley, and the Lower Lias of the Vale of Moreton. These have been previously discussed in some detail.

So far little has been said as to the relative ages of the various displacements here summarized and it is not proposed to discuss them all in detail, only the general conclusions being here given. In the first place it is quite clear that the uplift and denudation which gave rise to the present distribution of the Carboniferous rocks were in the main pre-Triassic, and over the Pennine area pre-Permian. Since these larger movements were almost certainly contemporaneous or nearly so over the whole area it follows that in the Midlands they were also pre-Permian or very early Permian, although from the absence of Permian rocks in the southern part of the area and the doubtful age of many red rocks in the northern and north-western Midlands it is perhaps impossible to give an absolute proof of this. Nevertheless the Trias has also undergone a good deal of disturbance, doubtless more than is actually realized, since faulting is very difficult to prove in such rocks as the Keuper Marls for example. Still in many cases Trias is clearly faulted against ancient rocks, e.g. Vale of Eden, North Stafford, Nuneaton, Malvern, and many more, though the actual post-Triassic displacement of these faults may not be great. But in many cases faults are known to have a much bigger throw in Coal-measures than in Trias. Now faults are also common in Jurassic rocks and the same line of argument applies.

It is perfectly clear that along many of the structural lines here described disturbance has taken place at different periods, often separated by long intervals of time, and in some instances the collective effect of frequent uplifts has been considerable, as in the case of the Market Weighton axis of Yorkshire. It is here sought to establish that the relations of the Mesozoic rocks over some of the old Charnoid axes are of a similar kind; also that such constant and successive elevations must in the end have measurable and even important effects on the depths at which Palaeozoic rocks lie in the same and in the intervening areas. Nevertheless, the chief value of the principles here set forth lies in the use of such repeated disturbances in Mesozoic times as *indicators* for the existence of buried trend-lines of older date, revealing the probable position of folds of much greater amplitude, now concealed from direct observation.

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[1] P. F. Kendall, "Cleat in Coal Seams": Geol. Mag., 1914, pp. 49–53. P. F. Kendall and H. E. Wroot, *Geology of Yorkshire*, 1924, pp. 130–1, and figures opposite, not numbered.

From a consideration of all the facts as here set out the following conclusion is drawn :—

The general structure of the Midlands is due to the superposition of a fanlike virgation of the Pennine axis on a pre-existing series of folds with N.W.–S.E. (*Charnoid*) *trend, the whole being limited on the west by the outer margin of the Caledonian fold-system, and on the south by the outer margin of the Armorican system, while on the east the relations are unknown.*

Thus in Armorican times the old rocks were subject to squeezing stresses between the competent Caledonian structures to the N.W., acting as a horst, and the Armorican earth-waves advancing from the south, while at or about the same time an uplift of the Pennine region in the north gave rise to strains which developed a virgate structure over the Midlands. On the eastern side these folds happened to coincide in direction with the ancient corrugations and accentuated them (e.g. Charnwood axis proper) thus accounting for their persistence throughout their whole length : to the west of the main axis, however, the two sets of folds crossed obliquely at various angles : at these crossing points were produced " areas of superelevation ", to use Haug's expressive phrase, and these gave rise to the inliers of older rock rising through the newer strata, which are so conspicuous a feature of that region.

It is quite possible that the facts here set forth and the conclusions drawn from them may have practical applications in connexion with the location of buried coalfields. In the past much money has been wasted in boring for coal in localities where a better knowledge of geological principles would have shown that there was no prospect of success. It would perhaps be invidious to mention actual examples, but such are well known to all geologists who have paid attention to this branch of their subject. As a matter of fact this investigation has been undertaken largely in the hope of adding to the general stock of knowledge on this point, and thus perhaps contributing in a small degree to the avoidance of uneconomic waste, and to the profitable development of the natural resources of the country.

The first obvious principle, which needs no elaboration, is that in Britain coalfields occur in synclines. Now the structural features here worked out are essentially anticlines, though some of them have passed over into faults. Hence it is clear that coal-basins are unlikely to be found on or near any of the anticlinal axes as indicated on the accompanying map. Here, however, it is necessary to guard against excessive dogmatism ; some of the evidence is capable of more than one interpretation and some of the conclusions are frankly speculative. Nevertheless it is believed that the probability of the correctness of the ideas here put forward is fairly high. Consequently it follows that the likelihood of finding a buried coalfield increases as we depart from any of the axial lines.[1]

Here, however, another important consideration comes in. So far none of the borings in the area north of the Thames and east of Burford in Oxfordshire have yielded any evidence of the existence of Coal-measures, at least of the productive type. (The Carboniferous rocks under Northampton are of very peculiar character.) It seems highly probable therefore that this part of the ancient plateau consists essentially of Devonian and older strata, and it becomes important to determine the approximate limits of this mass. The evidence cannot here be repeated in detail, but on careful consideration of all the facts it seems very improbable that productive Coal-measures will be found within a triangular area bounded approximately by the line from Folkestone to Westbury on the south and a line parallel to the present Chalk escarpment but lying a few miles to the north-west of it; this area is therefore provisionally written off as hopeless, though it is just possible that a tongue of Carboniferous rocks might occur in the Saffron Walden depression.

Professor Lapworth considered that the original limit towards the south of the area of deposition of workable coals lies along an arcuate line, ranging from the south-western end of the Shrewsbury coalfield, south of the Forest of Wyre, the Lickey Hills and Coventry, towards Leicester and the southern extremity of Charnwood Forest.[2] This estimate, however, seems unduly pessimistic; it is certainly a fact that the Carboniferous rocks below Northampton show no signs of coal, and the Coal-measures of the Burford boring in Oxfordshire are thin and unpromising; nevertheless, it is unsafe to assume that no coal was deposited in the comparatively large area to the north-west of this line which has apparently never been tested, since we know that coal-formation went on to a very late date in the Radstock coalfield, while Burford is in point of fact quite near to a region which on the ideas here set forth is distinctly unpromising; in fact, Burford is almost exactly on the line of the Pennine anticline and very near the line of the Lickey Hills and it is surprising to find any Coal-measures there at all. This must be regarded as one of the less propitious localities. The same remarks apply to the Batsford boring, near Moreton-in-the-Marsh, which is not very far to the north and still nearer to the Lickey line.

It is suggested, therefore, that there is a possibility of the occurrence of workable coals somewhat to the south of Professor Lapworth's limit in certain areas, namely in synclines lying between the prolongations of the Charnwood, Nuneaton (and Lickey) axes, especially in the areas where these presumed synclines are not subject to interference by the elements of the Pennine fan.

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[1] Walcot Gibson, "The Search for Coal beneath the Red Rocks of the Midland Counties": *Summary of Progress of the Geological Survey for* **1904**, *Mem. Geol. Surv.*, **1905**, **pp. 145–53.**

[2] *Final Report Coal Commission*, **1905, p. 5.**

On referring to the map (Fig. 3) it will be seen that a large triangular area, bounded by lines joining Tamworth, Andover, and Tunbridge Wells, appears to be free from anticlinal structures, although an underground continuation of the Lickey axis is not excluded. However, from the evidence of the borings at Calvert and various points connected with the detailed stratigraphy of the Jurassic rocks, the present writer is inclined to believe in the existence of another Charnoid axis, not established by clear evidence, but lying more or less along the line Warwick-Calvert-Aylesbury, and just east of Windsor. This line, if eventually established, would limit somewhat the possible area of exploitation. Taking this into account, then, one of the most promising areas seems to be in north Oxfordshire, between Bicester, Banbury, and Chipping Norton, as well as in the south of Warwickshire. Furthermore, the north-west corner of Berkshire seems promising, as also does most of the Cotteswold area. Here the obvious thinning out of the Coal-measures at Burford must be taken into account. So far as North Wilts and Gloucestershire are concerned it is necessary to consider the probability of a south-eastern extension of the Woolhope-Mayhill line, after crossing the Malvern axis, but the area south of Chippenham seems to be very favourably situated. A recent boring has struck Carboniferous limestone below Rhaetic at Lucknam, north of Box.[1] This point lies exactly on the strike of the small anticlinal ridge that runs due east from Bristol, through Wick Rocks, north of Bath. It seems probable that this small anticline may continue to the east, just under the town of Chippenham itself, but it is not of great importance, and cannot affect the area to the south and south-east towards Trowbridge and Devizes. In point of fact this region shows special advantages ; it is not far from the visible Bristol and Radstock coalfields and it is also clear of the line parallel to the Chiltern Hills, which, probably by the merest accident, seems to indicate the north-western limit of the area of ancient rocks at comparatively small depths. There is every reason to postulate the existence of a series of coal-basins along the northern side of the Armorican limiting zone, between Dover and Radstock, in the areas where a synclinal structure is not excluded by the incidence of the Charnoid and Pennine axes. The positions of these favourable areas are obvious from the map and need not be set out in detail.

With regard to East Anglia, facts are too scanty to allow even of speculation. We have the positive evidence of the old rocks at Culford, around Harwich, and at Lowestoft, but nothing more. The general absence of highest Jurassic and lowest Cretaceous strata (Portlandian-Wealden inclusive), and the character of the

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[1] "Thicknesses of Strata": *Mem. Geol. Surv.*, 1916, table facing p. 144.

Lower Cretaceous strata south of the Wash, indicate the proximity of land in Upper Jurassic and Lower Cretaceous times, and even the Albian of Norfolk (Hunstanton Red Rock) is probably a very shallow-water deposit. However, there is little to indicate the character of this land, though the petrography of the Lower Greensand is distinctly suggestive of derivation from Millstone Grit and Coal-measures rather than from Lower Palaeozoic or Pre-Cambrian rocks.[1] It is, however, possible that Professor Kendall's Willoughby axis is continued into eastern Norfolk and Suffolk.[2] Nevertheless, it seems very unlikely that coal will ever be found in Norfolk and Suffolk, though there may be possibilities under the Fenland. However, the evidence is so vague that it would be impossible to recommend any particular place for a trial boring to the N.E. of the line of the Charnwood axis and south of the Wash.

A point of some interest, though really outside the scope of the present paper, arises in connexion with the relation of the Charnwood axis to the Dover coalfield.[3] It will be recollected that this axis is defined by the Charnwood anticline itself, by borings at Leicester, Orton (Harrington), and the Sandy anticline. This line when continued coincides with points at which Silurian rocks have been struck at Ware, at Cliffe, in the Thames estuary, and at Chilham, west of Canterbury. The facts are highly suggestive of a ridge of ancient rocks running in this direction which if continued would pass out to sea a little west of Folkestone. This forms a natural and reasonable boundary to the Dover coalfield on the south-west, as shown by the Brabourne boring, where supposed Devonian, or at any rate Pre-Carboniferous rocks were encountered, although the general south-westerly slope of the Palaeozoic floor suggests that the influence of the Midland axes is here dying out.

In conclusion I would like to express my hearty thanks to Professor Marr for the patience which he has shown in listening to endless conversation on the subject of this paper and for helpful and illuminating suggestions and criticisms. I am also deeply indebted to Mr. W. B. R. King for his kindness in drawing the figures and pointing out one or two errors and omissions in my work.

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[1] Most of the metamorphic minerals in the Lower Greensand are very much rounded, looking as if they were second-hand, and not derived directly from crystalline schists. There are marked differences between the heavy minerals of the Norfolk and Bedfordshire areas, showing derivation from different sources. The very abundant iron oxide may also have been supplied from the denudation of Coal-measure ironstones.

[2] See H. A. Baker, "Evidence Suggestive of Charnian Movement in East Kent": Geol. Mag., 1917, pp. 398–403. This author suggests the existence of another Charnoid ridge, running under Suffolk, and outside of East Kent. This point is not discussed in the present paper.

[3] H. A. Baker, loc. cit.

Recent Changes in the Teifi Estuary.

By M. P. Latter, B.A., F.G.S.

WITHIN the last 50 years the lower reaches of the Teifi from St. Dogmells to Cardigan Bar have undergone a complete change: the bed of the river formerly lay near the west side of the estuary as far as the Webley Arms, and this point in the river was then known as Pwll Cam ("the crooked pool"), as it was here that the river took a sharp bend describing an ogee curve by way of the spit to the east of the present sandbanks: this old river channel lay in clay, unlike the present shallow river bed on the east side of the estuary, and quite big vessels could float even at low tide in front of the Webley Arms, which is now a low stretch of mud banks covered at high tide. A wreck, which laid up over two or three tides, was the simple means of effecting this change in the river's course. Since then it has led to other comparatively rapid geological changes: the Manian-fâch stream, which has its source in the Pant-y-Groes plateau, used to flow almost direct into the Teifi, when in its old course; now, however, since the bed of the Teifi, on leaving the Battery Point, crosses over to the east side of the estuary, the whole of the estuary to the west has been silted up with sand and mud, and this has been accelerated by the formation of sand-banks right across the mouth of the bay: consequently the Manian-fâch stream, on emerging off the mainland, is now deflected to the S.E. and flows for about a mile approximately parallel to the main river, though in the opposite direction, before joining it nearby the Battery Point. The watershed of the roughly triangular strip of sand flats, seen at low tide, lies very close to the present river bed, so that practically all the water off this area at low tide drains first into the Manian-fâch, and thus describes nearly a complete circle twice daily. This instance is analogous to, but not quite homologous with, that of the River Alde in Suffolk, the original mouth of which has been deflected more than 12 miles south by currents from the north.

Before the present line of sand-banks was formed, there existed a small area of sand dunes just to the west, from which the shore sloped down to the old river's edge: this is now an integral part of the present area of dunes, although a sharp line of demarcation can be drawn between the old and new deposits, on account of the marked difference in colour. Thus, at some period or other, a change of direction in the prevailing winds for the time held up any progress in the formation of dunes; the shifting of the channel of the river could hardly have had any effect, as it is at this point, i.e. just east of the present sand-dunes, that the new bed rejoins the old before crossing the bar.

Petrological Notes on a Porphyry from the "Seven Stones", Scilly Isles.

By Henry B. Milner, M.A.

DURING the course of work on the Pliocene deposits of West Cornwall, the writer had occasion to search a wide area for specimens of that increasingly rare but fascinating rock, the Wolf Rock phonolite. Inquiries were mainly confined to the most likely places for securing such material, apart from the rock itself, i.e. at the cottages of fishermen accustomed to work among the dangerous reefs off Lands End and the Scilly Isles. Although personal efforts to find such specimens proved by no means abortive, it was ultimately through the good offices of the Honorary Secretary and Curator of the Royal Geological Society of Cornwall, Mr. J. B. Cornish, that excellent specimens of the Wolf Rock phonolite, Longships schist, and Seven Stones porphyry were obtained from a local inhabitant, who apparently had an eye for novelties to adorn his domestic mantelpiece.

The Wolf Rock phonolite is classical and calls for no further remark here. Less is known of the Longships rocks, though it is not the writer's intention to deal with these at the moment. The following notes describe more particularly an interesting quartz-porphyry obtained from one of the rocks of a group known as the Seven Stones.

The name Seven Stones is somewhat of a paradox since there are several rocks forming this dangerous reef, though most are completely submerged. Six of the rocks have names by which they are known to mariners, the South Stone (5′), Flemish Ledges (submerged), Flat Ledge (4′), The Town (submerged), Pollard Rock (8′), and North-East Rocks (4′ to 5′); the figures in parentheses indicate approximate amount of the rocks uncovered at low tide. The most important is the Pollard Rock, whose precise position is lat. 50° 2′ 33″ N., long. 6° 7′ 40″ W. The whole reef lies 7·5 miles[1] N. 72° E. of St. Martins, Scilly Isles, and 16 miles W. 14° N. of Lands End. An inspection of H.M. Admiralty Hydrographic Charts No. 2565 (edit. 1920) and large scale inset on No. 1168 (edit. 1917) shows that the reef is approximately $\frac{3}{4}$ mile long by $\frac{1}{3}$ mile broad, having an average depth of 7 fathoms of water covering it, save where the particular rocks mentioned occur. A reconstruction of the submarine contours from the recorded depths around the reef show that it drops fairly steeply away at its edges into 25 to 27 fathoms, and that it has a submarine topography comparable with that of some of the Scilly Isles. The rocks are for the most part inaccessible owing to the dangerous tide race and the heavy swell commonly prevalent here.

The specimen of porphyry measures approximately 3″ by 2″ by $\frac{3}{4}$″, and is superficially stained with seaweed dye in addition to limonite.

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[1] Geographical miles. Bearings relative to magnetic north (1920).

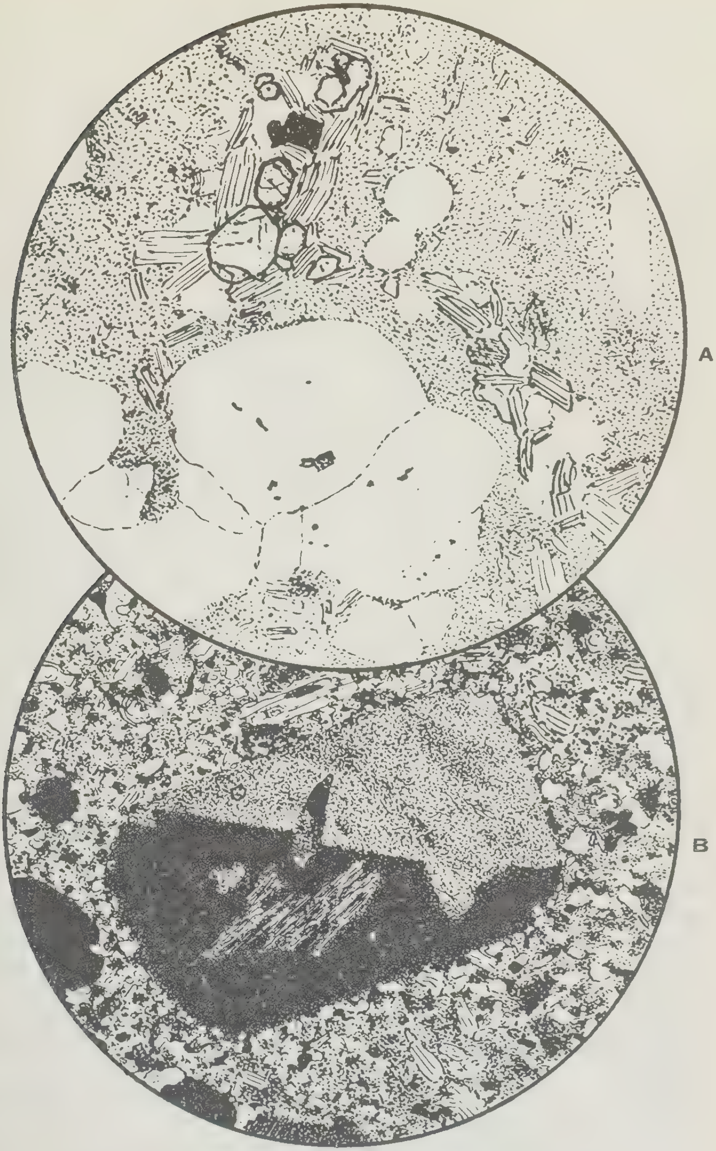

FIG. 1.—Quartz-porphyry (Elvan), Seven Stones Reef, Scilly Isles. A, Ordinary light: Quartz, apatite, brown and white mica, pyrites, etc. (× 40.) B, Polarized light: Orthoclase: Baveno twin. (× 40.)

Incrustations of polyzoa and a few serpulæ are conspicuous on its surface. The rock has a zone of weathering $\frac{1}{8}$ in. thick; apart from this, it is a grey, medium textured, porphyritic rock with quartz, felspar and pyrites crystals embedded in a finer matrix. Macroscopically it recalls some of the more compact granite porphyries of the Lands End district, especially the "Long Rock" elvan.[1]

Under the microscope this is an extremely pretty, though somewhat uncommon, type of porphyry. The phenocrysts of quartz tend to be euhedral but are much corroded; they are colourless and contain inclusions of apatite, zircon, tourmaline, biotite, fluid, and of the ground mass; in a few instances very perfect crystals of orthoclase were noted. The felspar, mainly clinopinacoidal in habit, is orthoclase, turbid with decomposition products, especially muscovite and kaolinite; a perthitic facies can sometimes be made out; both Carlsbad and Baveno twinning are observed (Fig. 1, B). The orthoclase also contains inclusions, notably biotite and apatite; the biotite, however, is much altered. There are some large bleached crystals of biotite showing every stage of alteration to chloritic matter with separation of rutile and iron oxide; this biotite encloses zircons with very weakly pleochroic haloes; it is often in intimate association with apatite which builds characteristic hexagonal or prismatic crystals of very low birefringence. Irregular aggregates of brownish green pinite (probably after cordierite) are recognizable. Much of the primary iron ore, believed to have been originally ilmenite, is represented by a complex of limonite and leucoxene.

The ground mass is composed of a uniform micro-granitic aggregate of quartz, orthoclase, brown and white mica, chloritic matter, apatite, a little tourmaline and frequent iron ore, mostly ilmenite.

The pyrites, which gives the character to this rock in hand specimen, is clearly of later origin, and ranges from 0·1 mm. to 3 mm. in size. The crystals have attempted simple cubic form, but they are often stunted in growth or assume triangular shapes. They seem to have developed haphazardly within the rock and are quite alien to its general structure.

Inquiries point to much of the Seven Stones reef as being granitic in nature, similar to the Scilly Isles type; it is thus reasonable to conclude that the porphyry is part of a dyke associated with the granite, though it is noteworthy that only two occurrences of quartz-porphyry (which may belong to one and the same dyke) have been recorded from the Scilly Isles (on St. Marys).[2]

The specimen in question has been handed over to the British Museum (Natural History).

The writer is indebted to Mr. G. M. Part for the accompanying figures drawn from two microscope slides of the porphyry.

[1] "Geol. of the Lands End District": *Mem. Geol. Surv.*, 1907, pp. 63–4.

[2] "Geol. of the Isles of Scilly": *Mem. Geol. Surv.*, 1906, p. 12.

Three Short Papers on Isostasy.

By W. B. WRIGHT.

I. THE ISOSTATIC LAG.

THE question of the supposed isostatic adjustment of the earth's crust to increase or decrease of load has recently come prominently to the fore in connexion with the Wegener hypothesis and Joly's theory of geological transgression and revolution. The principle itself is fairly well established by several independent lines of evidence, but there is room for clearer thinking as to the mechanism attending its operation. Very varied opinions are for instance held as to the rapidity and completeness of the adjustment, and unjustifiable assumptions are made with regard to the displacement of magma beneath depressed areas. It is very necessary to keep an open mind on these questions and to search the available evidence for means of defining the nature of the attendant subcrustal movements.

That there has been a very distinct lag in the recovery from the isostatic depression beneath the Quaternary ice-sheets is now a well-established fact which it is impossible to deny. Let us for the moment not theorize as to its cause, but contrast it with the remarkable state of affairs evidenced by the piling up in certain areas, during the great periods of geological accretion, of many thousands of feet of conformable shallow water sediments. We are here face to face with a repeated subsidence so delicately adjusted to the added thickness of sediment as to maintain the surface of the latter always approximately at sea-level. This is an almost incredibly delicate and rapid response to the added load. The facts, however, are so obvious that we can hardly deny the conclusion. We are led therefore to seek a reason why isostasy should at one geological period be rapid and exact in its action and at another as obviously tardy and imperfect. The apparent explanation is not far to seek and arises as a natural corollary from Joly's theory referred to above.

This theory, it will be recalled, insists on the necessity of a periodic accumulation of radio-actively generated heat in the subcrustal magma, whereby the latter is reduced from a condition of semi-solidity to a relatively fluid state. Convection then sets in; the crust is locally thinned by melting and becomes more mobile; excessive vulcanicity and mountain building ensue, and there is a period of rapid escape of heat until the magma cools once more and partially solidifies. During the earlier phases of this cycle the magma slowly decreases in specific gravity and the floating continents sink deeper into it, so that the sea transgresses over the continental shelves and low-lying areas. A reason for the approximate simultaneity of transgression the world over is thus for the first time offered, and incidentally the contrast between the Quaternary isostasy and that of the great periods of sedimentation becomes susceptible of explanation. As the subcrustal magma increases its fluidity the response to loading becomes more exact and immediate, so that the addition of a small thickness of sediment is compensated at once by an equivalent sinking. In a period such as the Quaternary which followed upon a great revolution, the magma may be presumed to have been at or near the phase of greatest partial solidity, and to have had properties analogous to viscosity, which would retard the isostatic adjustment. Whatever be the nature of the subcrustal movement, which renders possible the depression of the earth's crust beneath a load, it must clearly be retarded by a state of semi-solidity in the magma below the crust.

It would seem therefore to be consistent with our present partial knowledge of isostasy to regard it as a variable factor which is more rapidly effective in the periods of transgression than at other stages of the earth's history. There is no doubt an attendant change in the character of the sedimentation, but in view of the other modifications caused by the alternation of transgression and revolution it is difficult to say in exactly what way it might be expected to show itself in the geological record.

II. The Wave-like Progress of the Emergence.

One of the most undeniable and most interesting of the facts connected with the isostatic recovery from the load of the Quaternary ice-sheets is what is known as the " wave-like progress of the uplift ", which started first in the peripheral regions and gradually crept inwards in the wake of the retreating ice. This has been clearly established both in Scandinavia by Brögger and in America by Warren Upham. Unfortunately, the ultimate meaning of the phenomenon is not so obvious. It is almost universally agreed that it is one of the effects of the lag discussed in the first article of this series. Recovery naturally sets in earliest in the peripheral regions, which were first cleared of the ice. The matter is, however, complicated by another effect. It has been amply proved by Brögger in Christiania and by Johnston in the St. Lawrence Valley that submergence followed immediately on the retreat of the ice. To regard this as the effect of lag is, of course, possible, since adjustment must go on until a state of balance is reached, but at the date of the initial submergence in the Christiania fjord the ice-sheet had shrunk to a very small fraction of its maximum size, so that we must suppose that, even at this late date, less than this small fraction of the total load had been compensated, a view not easily harmonized with our conceptions of the length of the Ice Age. No question of momentum such as would carry the movement beyond the point of equilibrium enters into the matter. Such a slow movement cannot be supposed to have any appreciable momentum.

A much simpler explanation of the initial submergence is obtained by introducing the idea of eustatic movements of the sea-level produced by some such cause as a change in the volume of the ocean basins or the return of the great volumes of water imprisoned in the ice-sheets. The writer has elsewhere shown[1] that all the complicated effects of late-glacial and post-glacial elevation and depression in the region of Scandinavia and the Baltic can be explained in terms of continuous isostatic recovery from the effects of the ice load combined with a rising of sea-level with one simple oscillation. The recorded facts in the British Isles are, with certain puzzling exceptions, susceptible of a similar explanation, and those in America also fall into line. The theory as a matter of fact guided Mr. W. A. Johnston[2] to search for the evidence of initial submergence in the St. Lawrence region and thus justified itself by prediction.

The lag and the inward wave-like progress of the uplift are none the less undeniable, even though we cannot reasonably ascribe the initial submergence to them. We may presume that the imposition of the load is accompanied by a similarly delayed wave-like depression travelling outwards. When, however, we come to speculate as to what happens to the magma displaced by the depression we are on very unsafe ground. It may, as suggested by Professor Daly and later by Professor Kendall, travel laterally outwards and produce a ring of elevation around the ice-sheet or other load, but the adjustment may also be deep-seated and on such a scale as to produce no noticeable effect of this kind. It all depends on the depth of the magma basin and the mobility of the magma. No a priori argument is of any avail, and no conclusive evidence one way or the other has yet been produced. Daly was of opinion that the temporary ring of elevation might be detected by reversals of drainage, and he cited a few cases possibly ascribable to this cause, while Kendall suggested that it might be responsible for the proved emergence of the pre-glacial shoreline on the approach of the ice. Daly's evidence is not of a convincing kind and he does not himself press it, and the emergence of the shoreline may more reasonably, in view of its wide distribution, be ascribed to lowering of the sea-level caused by the binding up of water in the ice-sheets.

The occurrence of the peripheral ring of elevation is therefore neither an established fact nor a necessary conclusion. It does not follow as a consequence of the wave-like progress of the uplift, for the latter finds a simpler explanation in the lag in recovery, due to viscosity and partial solidity, than in the lateral creeping in of a subcrustal magma.

When we have got some evidence either for the occurrence or non-occurrence of this presumed peripheral ring of elevation we shall have another clue to the depth and fluidity of the magma, the presence of which the phenomenon of isostasy seems clearly to indicate.

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[1] *The Quaternary Ice Age*, Macmillan, 1914.

[2] Geol. Survey of Canada, *Museum Bulletin* No. 23.

III. The Azilians of Oban.

It was pointed out in the last article of this series that the phenomenon of initial submergence indicated an oscillating sea-level. There are other facts, such as the distribution of the submerged forests and the freeing of the outlet of the Ancylus Lake, which point in the same direction. Having therefore to deal with the inter-relation of two elements, both moving, it cannot lead to clear thinking to refer the motion of one to the other. Emergence of the land no longer implies elevation, nor submergence depression. Let us in future refer all movements, whether of the sea or land, to an ideal surface, which may have any desired radius but may conveniently be regarded as parallel to the sea-level of the present day. Regarded in this way the motions of land and sea may be represented by curves as in Fig. 1. The recovery of the land is shown as beginning slowly, reaching a maximum rate, and then falling off; the rise of the sea as being well under way when the recovery of the land was starting and as falling off in time until interrupted by a single oscillation. The sea curve is, as a first approximation, assumed to be the same everywhere. The land curve has to be given a different amplitude and time relation according to whether we are considering central or peripheral areas. The relative inclinations of the land and sea curves now give the apparent motions of submergence and emergence. Where the curves are diverging the land is emerging, where they are converging it is undergoing submergence, and where they are parallel there is no relative motion and a well-marked shoreline is cut.

These curves, it will be noted, are relatively simple. The observed phenomena of which they serve as an interpretation are really amazingly complex. It is impossible to explain in detail in so short an article as the present to what extent there is agreement with observation, or to emphasize those facts which are not explained, of which there are undeniably a few. The following notes may serve as a guide to anyone who wishes to follow out on the diagram the actual scope of the theory.

(1) In Scotland and peripheral Scandinavia there was post-glacial resubmergence (Neolithic or 25 ft. beach, Littorina–Tapes Sea) without any reloading to explain it. The explanation of this is apparent on combining curves S and L_1.

(2) In central Scandinavia there was no post-glacial resubmergence, but a slowing up of emergence has been proved, preceded by an acceleration of the same. Curves S and L_3.

(3) Along a line between these two areas (the Mjösensee Line) a prolonged halt has been proved, preceded by an acceleration of emergence. Curves S and L_2.

(4) In Scandinavia and Canada the first observed relative motion of land and sea was submergence. This was established by Brögger in Scandinavia, and subsequently, as a direct result of the publication of the present theory, by Johnston in Canada. A similar submergence probably occurred in Scotland, but the smallness of the elevation prevents proof or disproof. The phenomenon is seen to be due to the sea recovery

beating the land recovery in the early stages. Curves S and L_1, L_2, and L_3.

(5) In Scandinavia the maximum of late glacial submergence occurred much later, as proved by correlation of faunas, in the central than in the peripheral districts.

(6) Outside the isostatically depressed areas the only relative motion of land and sea that has been proved was progressive submergence from earliest submerged forest times onwards.

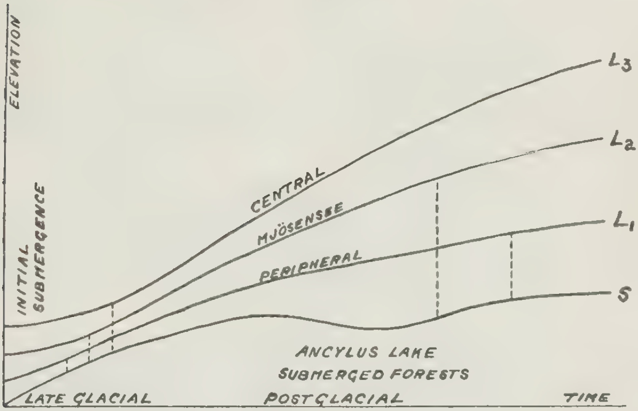

FIG. 1.—Diagram showing the character of the relative motion of land and sea in late-glacial and post-glacial times in Fennoscandia. Quantitative representation is not attempted, and the form and relative position of the curves are all that are intended to carry meaning.

The theory as yet affords no explanation of the following facts :—

(1) The 100 ft. beach of Scotland, marking the maximum of late-glacial submergence, does not appear to descend to sea-level at the periphery of its area of distribution as does the shoreline of the Yoldia Sea, but disappears suddenly while still at the elevation of approximately 100 ft. No explanation has been found for this.

(2) On the Lancashire and Cheshire coasts there are two submerged forests, one beneath the deposits of the "25 ft." beach and one above them. This relation has not been observed elsewhere.

(3) Finally, in America the Micmac shoreline, which seems to represent the post-glacial maximum of resubmergence in Europe, shows, as far as it has been traced, no isostatic deformation. It is definitely known, however, only along the southern shore of the St. Lawrence, and this coast may coincide with an isobase.

Having thus indicated the merits and confessed to the weaknesses of the theory, we are now in a position to proceed to the discussion of a point the significance of which has, I think, never been appreciated.

It has long been a matter of general knowledge that the implements left by Neolithic man in the British Isles and Scandinavia bear very definite relations to the successive post-glacial shorelines. The facts are due to du Noyer and Praeger in Ireland, to Anderson in Scotland, and to Brögger in Norway. In Norway the roughhewn axe-head of the type known variously as Campignien, Larne, or Nöstvet is found associated with the shoreline of the maximum Littorina-Tapes depression, and polished axe-heads of progressively more advanced type with the successive lower shorelines.

In the British Isles a similar relation has long been observed, and although the amplitude of the oscillation does not permit of the beautifully detailed subdivision attained by Brögger, yet a distinct advantage is gained in the presence of the Azilian industry, not up to the present proved in relation to the beaches of Scandinavia. The facts available are briefly as follows :—

> In the caves formed during the maximum of the post-glacial re-submergence at Oban on the west coast of Scotland, Azilian implements have been found in a culture layer interstratified with the uppermost portion of the beach shingle.
>
> In the shingle spit formed during the same maximum at Larne, Campignien implements are interbedded with the gravel.
>
> In numerous localities Neolithic implements of more advanced type, including in some instances polished stone axe-heads, are found resting on the surface of the raised beach and extending out over this surface down to levels not very clearly determinable but much lower than the maximum of submergence.

It is around the first two facts that interest centres. The Azilian is universally regarded as ante-dating the Campignien, and since the Azilians could hardly have occupied the Oban caves until some slight recession had raised them a little beyond the reach of any but exceptional storms, it would appear that emergence set in earlier at Oban, i.e. near the isostatic centre, than at Larne, further out. In other words, there is demonstrated a wave-like progress of the emergence from the central area of depression outwards, a result which seems at first sight to be in violent conflict with accepted ideas of isostatic recovery. That there is no such conflict will, however, appear on referring to Fig. 2, which shows the recovery curves for Oban and Larne (A and B) in relation to the general sea-level curve S. It will be noted that the parallelism between A and S, which gives the maximum of submergence at Oban, takes place at an earlier date than that between B and S giving the maximum at Larne. The theory therefore explains this additional relation without any modification of the form of the curves constructed to fit an entirely different series of facts. That it should do so gives one confidence to generalize from the Oban-Larne time relation, and predict an even later date for the maximum in the extreme peripheral portions of the beach. Future research may bring to the test of this prediction two lines of evidence :—

> (1) The later Neolithic implements found far out on the surface of the beach in Scotland, North-Eastern Ireland, and the Isle of Man may be more and more restricted to its inner margin towards the periphery, where they would tend finally to be excluded from its surface altogether.
>
> (2) The fauna associated with the maximum of submergence in the peripheral areas might show that this maximum was later than the post-glacial climatic optimum, which Praeger has shown was contemporaneous with the maximum at Larne and Belfast.

The relatively shallow depth of the proved submerged forests within the isostatically affected area of Great Britain and the reduction of the depth of submergence to a few feet below high watermark in the fjords of Western Scotland, although a fact of a somewhat negative character, agrees well with the idea that the maximum of post-glacial submergence in this central area must be pushed back to very near the second point of inflection of the curve S. Places where the curves of recovery are of such form as to be parallel to S at this point of inflection are comparable to those along the Mjösensee line in the Christiania Fjord and are marked by a very prolonged halt but no resubmergence. Within such a line there would be no submerged forests at all. There may be such an area in Scotland, but it is very limited. In Scandinavia there is an extensive area within the Mjösensee line, throughout which continuous emergence has prevailed since the Yoldia maximum.

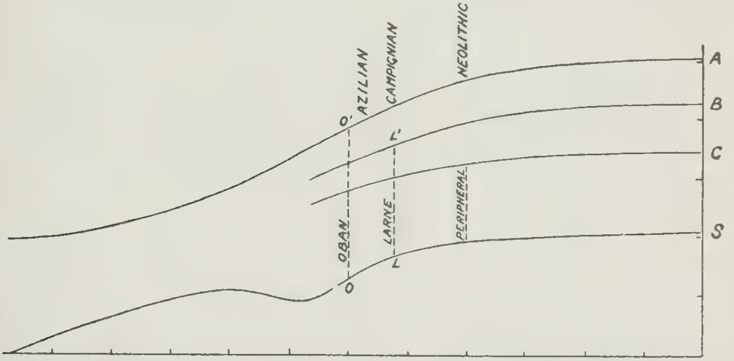

Fig. 2.—Diagram showing the relative motions of the land and sea in the British Isles in late glacial and post-glacial times. An attempt is made to introduce measurement into this figure so as to give the beaches and submerged forests their correct relation to sea level at the present day and to define roughly their dates of formation. Subdivisions on the vertical axis represent roughly hundreds of feet and those on the horizontal axis may be regarded as having values ranging from 1,000 to 1,500 years. The broken lines joining the curves indicate the points of parallelism.

An observation recently made by Mr. E. B. Bailey seems also to fall into line. The island of Mull on the west coast of Scotland lies in an area where the isobases of the post-glacial beach are closely crowded together so that the south-eastern side of the island is in the central area of the beach while the north-western is relatively peripheral. Mr. Bailey has noted that the beach on the south-east is powerfully developed and clearly defined, while on the north-west it is weak and indefinite. It is difficult to say with any confidence from such observations as are available whether the relation is general all round the depressed area, because where the isobases are less crowded the change is less rapid and variation in local conditions makes comparison hazardous. It is interesting to note, however, that the theory outlined in this article indicates that a more sharply defined shoreline is to be expected in the central area than in those round about, for it is clear that the curves A and S retain their parallelism at O and O′ considerably longer than B and S do at LL′ because of the greater difference in curvature at these latter points.

Whether a renewed accentuation is to be expected in the extreme peripheral areas is more doubtful. The curves certainly seem to indicate it and it will be interesting to see whether the outer islands off the west coast of Scotland show any effect of the kind. This prediction and that relating to the supposed late Neolithic date for the maximum in the peripheral areas are, however, rendered unsatisfactory by the possibility of minor oscillations in the curve C, of an amplitude insufficient to affect any of the main conclusions from the theory, but quite adequate to alter both the date and character of the maximum in areas where the total emergence is at most only a few feet.

REVIEWS.

Elemente der Gesteinslehre. By A. Osann and H. Rosenbusch. Vierte, neu bearbeitete Auflage. pp. 779. 1 Hälfte, 1922; 2 Hälfte, 1923.

THE fourth edition of H. Rosenbusch's memorable "Elemente der Gesteinslehre" has recently appeared revised and rewritten by Professor A. Osann. The last edition was published in 1910, and it is interesting to note the changes of view that have occurred in the intervening twelve years. Professor Osann has brought the work up to date in so far as he has been able to consult non-German, or rather ex-enemy, literature. He states in the foreword how difficult it has been to gain access to literature published during the Great War, and apologizes for the inevitable omissions which have thus occurred. There is little or no need for apology. Professor Osann has built around Rosenbusch's book what is unquestionably the finest textbook of *petrography* and petrographic reference in existence. *Petrology* is indeed not neglected; on the contrary it is well done, but it is subordinate to the purely descriptive and classificatory side of the science.

The book makes a closely-packed volume of 779 pages, with 115 illustrations. 300 analyses of rock-forming minerals and no less than 1,350 analyses of rocks are quoted. It may be mentioned here that, while extremely useful average chemical analyses of many igneous rock types are computed in the first volume from the analyses given, they are unfortunately discontinued for some reason in the second volume. Nevertheless the averages (for the plutonic igneous rocks only) afford a good complement to Daly's averages. It is interesting to find that Osann's averages, based on different numbers and assemblages of rocks, correspond quite closely to Daly's, a fact which speaks for the distinctness and solidarity of many rock types, the average composition of which may be taken as representing the consensus of opinion of many petrographers regarding their respective contents and limitations.

In his foreword Professor Osann states that the arrangement of the material remains the same as in the last edition, save for unimportant alterations. The contact-metamorphic rocks, for example, are dealt with in the third section of the book along with other metamorphic rocks, instead of being appended to the igneous rocks responsible for the alteration. The general petrological matter has been largely rewritten in order to bring it into conformity with present-day views.

It is illustrative of the difficulty of access to foreign literature in Germany that Osann does not mention Washington's latest (1917) collection of igneous rock analyses in listing such collections (p. 6); and that he uses Clarke's 1911 figures for the average composition of the crust instead of the later and more accurate figures published by Clarke and Washington in 1922.

Daly's views as to the origin of the Moyie sill are accepted in unawareness of Schofield's later work.

The terms structure and texture in igneous rocks (p. 55) are defined by Osann (and formerly by Rosenbusch) with meanings practically opposite to British and American usage. *Structure* is defined as those relations determined by form and size in the *mineral* development of the rock; *texture*, however, is conditioned by the kind and manner of spatial arrangement in the rock. Under the heading of structure are treated the degree of crystallinity, absolute grain size, and the various arrangements of minerals which have been included by American petrographers under the term *fabric*; under texture we find orbicular and flow phenomena described, as well as vesicular and miarolitic structures.

Essential modifications of Rosenbusch's scheme of classification have not been made. It still remains a qualitative classification based first on geological position, structure (texture), and finally mineral and chemical composition. Osann attempts to give it a quantitative basis by applying his well-known chemical method through the recalculation of analyses, and locating the rocks, or rather the analyses, within the sextants of his triangular projection; but without much success so far as the writer can see.

In the descriptive part of the work we may note first the extremely useful concise histories of the various rock names as they arise. Granodiorite and monzonite are prominent absentees from the list of plutonic rock families. The former is treated under the diorites, along with tonalite, as a modification of quartz-diorite. Osann notes the abundance of quartz in these rocks, which the reviewer would suggest is the main difference from quartz-diorites. He would therefore rather ascribe granodiorite and tonalite to the granite than to the diorite family. Monzonites are described under the syenites.

The statement that "the syenites are closely attached to the corresponding granites, and are connected with them by numerous transitions in chemical and mineral composition and in field occurrence; they are silica-poor forms of the granitic magmas" is one that may be challenged. In our opinion, the only granites in which transitions to syenite are at all common are the soda-granites.

Osann points out that Ramsay's original *umptekite* is only a kind of endomorphic contact facies of nepheline-syenite. Had he had access to recent literature he would have also noted that the original *essexite* of Salem, Mass., consists partly of contact-metamorphosed gabbros, and partly of hybrid rocks due to the mixing of gabbro and nepheline-syenite.

With regard to the definition of diorite, Osann throws over the old view based on the presence of biotite and hornblende rather than pyroxenes as the predominant coloured minerals, and states that in the plagioclasic plutonic rocks the term diorite is now applied to the more acid, and gabbro to the more basic, members. Diorites are distinguished from gabbros by containing a more sodic plagioclase, a smaller amount of bisilicates, and often a little quartz. Gabbros, on the other hand, frequently carry olivine.

In the last edition of the *Gesteinslehre*, Rosenbusch placed the charnockite series, as Osann says (p. 241), "in a certain parallelism with the alkalic and calc-alkalic series"; but in its chemical characters it links up with the calc-alkalic series, and there is no need to erect a new series.

In dealing with pyroxenites we note incidentally that Loch Garabal is placed in Sutherlandshire (p. 254), a mistake arising no doubt by confusion with Loch Borolan. *Rockallite* is described as a quartz-tinguaite or grorudite, which ascription is clearly based on Judd's erroneous description of the rock as a sill. That *heronite* has been demonstrated to be only an analcitized tinguaite is not known to Osann. It is possible to challenge the relegation of *beerbachite* to the lamprophyres. From its mineralogical composition and texture it seems to be the aplitic form of melanocratic gabbros and eucrites.

The fact that the age basis is still used in German petrological nomenclature becomes evident in the description of the volcanic rocks, where the terms quartz-porphyry, porphyrite, melaphyre, are still used for the Pre-Cainozoic examples of rhyolite, andesite, and basalt. A defence of this is attempted, as can be seen from the following quotation: "In later years the distinction between melaphyre (Pre-Tertiary—Carboniferous and Permian) and diabase (Older Palaeozoic) has tended to become effaced, so that Mesodiabases have been described. Since German diabases occur in fold-mountain ranges they have had impressed on them characters which differentiate them sharply from the normal basalt and melaphyre types. Where, as in Sweden, the diabases occur in unfolded Silurian, they show the normal basalt and melaphyre characters. Their distribution in mountain ranges and varying characters justify a separate treatment of diabases."

Alkali-diabases, essexite-diabases, and theralite-diabases are treated separately from the calc-alkali-diabases. *Teschenite* is regarded as an analcite-bearing theralite-diabase, in which the analcite has arisen as an alteration product of nepheline. *Spilite* is treated under diabase, and no mention is made of the "spilitic suite" or of the presence of sodic plagioclase in this type.

A welcome innovation is the recognition of a group of alkali-andesites or trachyandesites, for rocks of andesitic character which have a mildly alkalic cast. In this group we find the Drachenfels and Ponza trachytes, many of the Auvergne andesites, some latites, hauyn-andesites, etc. There are transitions on the one hand to the alkali-trachytes, and on the other hand to the trachybasalts (trachydolerites).

The treatment of the sedimentary rocks has suffered practically no change in this edition. It occupies only two more pages than in the former edition ; the section on salt deposits has been expanded ; a paragraph on the rounding of mineral grains has been inserted ; and the former section on porphyroids has been relegated, as a paragraph only, to the description of rhyolites. This portion remains, as before, the least valuable part of the textbook.

Much new material, however, has been incorporated into the third part of the book, dealing with the crystalline schists, as is shown by an increase in length of 41 pages. The general matter has been entirely recast, and especial prominence is given to the work of V. M. Goldschmidt and P. Niggli. The whole subject is treated from the thermodynamic standpoint, and the discussion is most valuable, as it summarizes much of the newer Continental work on metamorphism and metamorphic rocks. The descriptive matter is less changed. Sections on nepheline-syenite-gneiss and on leptite, are inserted ; and certain separated groups of schists in Rosenbusch's classification are now treated under the "Kalk series" and the "Magnesia-series".

About 14 pages of short notices of recently described rocks, some British, form an appendix to the work.

For students who can read German the *Gesteinslehre* remains, in our opinion, the best available textbook of petrographic reference. Rosenbusch lives again in Professor Osann's devoted work.

G. W. TYRRELL.

ON THE CHEMICAL COMPOSITION OF RUSSIAN PETROGRAPHICAL PROVINCES. (In Russian, with a French résumé.) By F. LOEWINSON-LESSING. Petrograd, 1924.

THE analyses of 660 Russian igneous rocks have been recalculated according to the author's formula, the results compared, and generalizations established. The principal result of that study leads to the conclusion that the division of igneous rocks into the Atlantic and the Pacific provinces does not find confirmation in Russia, where the alkaline rocks are usually co-present with calc-alkaline rocks. The alkaline rocks also often occur in regions of folding. All rocks of the principal Russian petrographical provinces, with the exception of Ural Mountains, Olonetz province, and Kola peninsula, have an average coefficient of acidity of 2·38, corresponding to the average coefficient of acidity calculated for all igneous rocks by Washington (2·39), and for the earth-crust by Clarke (2·41). According to the chemical classification of F. Loewinson-Lessing this coefficient of acidity corresponds to a quartz-diorite magma.

It is very interesting to notice that the average coefficient of acidity of Ural (1·75), Olonetz (1·66) and Kola (1·90) corresponds to the coefficient of acidity of rocks from the bottom of the Atlantic and Pacific oceans—1·77. (H. S. Washington. Chemistry of the Earth's Crust. *Smithsonian Report* for 1920.) The significance of this observation is still greater if we point out that the last three provinces belong to Caledonian and Hercynian mountain regions, and are deeply denuded, while the provinces with a high coefficient of acidity are located in regions of Tertiary mountain formation. Therefore, "if there is really a marked difference between the continental and oceanic chemical types, then Ural—an ancient geosyncline and an oceanic bottom, must belong to the latter type."

S. T.

ANNALS OF THE GEOCHEMICAL SECTION OF THE METALLURGICAL AND CHEMICAL SOCIETY AT THE PETROGRAD POLYTECHNICAL INSTITUTE. No. 1, 1924. pp. 94.

THIS publication of the Geochemical Section (first of its kind in Russia) contains 19 short papers dealing with various geochemical and geological questions. Besides original research there are several general accounts of modern developments in science.

A. Ginsberg and Ch. Nikogosian have contributed a paper on the binary system of sodium and calcium metasilicates, which form a continuous series of isomorphous solid solutions. The melting-point curve possesses one maximum corresponding to the compound $3CaSiO_3.2Na_2SiO_3$, with two minima on either side of it.

D. Scherbakoff gives some new data on the occurrence of radio-active minerals in Fergana (Turkestan), based on the results of a scientific expedition in 1922, of which he was a member. The uranium ore containing radium occurs in some caves in the lower Carboniferous limestone at Tyuya-Muyan. The ore, oxides of copper, uranium, and vanadium, was found impregnating the walls of limestone caves. Mineralogically, the ore was very little studied. Some new minerals have been previously described by Nenadkevitch, such as tyuyamunite ($CaO.2UO_3.V_2O_5.nH_2O$), alaite ($V_2O_5.H_2O$), turanite ($V_2O_5.5CuO.2H_2O$).

Apparently the ore is of hydro-thermal origin.

The estimated reserves of this ore are 5,000 tons (with 1 gramme of radium per 250–350 tons of the ore).

The total reserve of radium must amount, therefore, to 15–20 grammes.

Besides this deposit, radio-active ores are known to exist in various parts of Turkestan. A vanadium-nickel silicate ore is found in a black siliceous shale of Silurian age in the Alai mountains, and a number of radio-active minerals have been found in many other places.

The paper by D. Beliankin on the quantitative mineralogical analysis of syenite from Biella (Piemont), is an attempt to give a modal analysis of that particular rock by combining separate analyses of the rock, isolated minerals and the planimetric mechanical analysis. The results show that the Biella syenite is very closely related to the Plauen syenite, although the relative proportions of felspars (microcline, oligoclase) are different.

D. Beliankin also gave a very suggestive paper on liquid crystals and another in collaboration with V. Vlodavetz on the geological survey along the eastern shore of the Kola peninsula.

S. T.

OBITUARY.

John Herbert Milton, F.G.S., F.L.S.

The death of Mr. J. H. Milton, F.G.S., F.L.S., which occurred on 8th March, 1925, in his sixty-third year, will be deeply regretted by geologists throughout the country, among whom he was widely known and esteemed. For over forty-three years he had been connected with the Merchant Taylors' School, Crosby, Liverpool, where, at the time of his death, he held the position of senior master. Although not actively engaged in geological work, he took a deep interest in the science, and until recently was a familiar figure at meetings and excursions of the British Association and other societies. He was especially interested in the Carboniferous Limestone, and as President of the Liverpool Geological Society he devoted two addresses, which are published in its *Proceedings*, to its corals and brachiopods. A man of many social gifts and much charm of manner, he was an admirable leader of excursions, and will long be remembered by those who have enjoyed his companionship in the field.

T. A. J.

William Whitaker, B.A., F.R.S.

William Whitaker, who died on the 16th January, 1925, was by birth and education a Londoner, and it was fitting therefore that he was also pre-eminently the London geologist. The vaguely defined and heterogeneous deposits of the Chiltern country attracted his attention during part of his school days at St. Albans, and helped in forming his resolution to interpret them. After graduating B.A. at London University, he joined the staff of the Geological Survey in 1857, under the Directorship of Sir Roderick Murchison, and from thence until his retirement in 1896, most of his time was devoted to the mapping and the study of the Tertiary and Quaternary deposits of the south and east of England. He followed in the footsteps of Sir Joseph Prestwich, substantiating and augmenting the conclusions drawn by him. He had a passion for collecting records of sections of wells and temporary exposures and many of these have since been published by the Geological Survey in the series of Memoirs on the water supply of the counties. He was recognized as a leading authority on questions of water, and served on numerous committees and commissions dealing with both private and public supplies. Until the last much of his time and his colossal energy were devoted to the subject

He was the leading spirit for half a century of the London Geologists' Association, and as director of excursions was always popular and ever ready to help and guide. He served for two periods as President.

The original one-inch survey maps and the accompanying memoirs of the London Basin were largely the result of his work, and his memoirs on the "Thames Valley" and on "The Geology of London" will ever remain classics and form indispensable parts of the geologist's equipment.

His services to geology were freely recognized by the Geological Society, who awarded him the Murchison Medal in 1886, the Prestwich Medal in 1906, and the Wollaston Medal in 1923. He served as President from 1898 to 1900, and was elected a Fellow of the Royal Society in 1887.

All who had the privilege of knowing him will agree with Sir Aubrey Strahan's words: "Unselfishness, transparent honesty, and kindliness were the conspicuous features of his truly lovable nature."